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METALS RESEARCH


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FLAW GROWTH OF 7075, 7475, 7050 AND
7049 ALUMINUM ALLOY PLATE IN STRESS
CORROSION ENVIRONMENTS (CONTRACT
NAS8-30890): 4-YEAR MARINE
ATMOSPHERE RESULTS

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ABSTRACT

After nearly 53 months of exposure to marine atmosphere, crack growth in SL DCB specimens from 7075, 7475, 7050, and 7049-T7X plate has slowed to the arbitrary 10^{-10} m/sec used to define threshold stress intensity (K_{Isc}). In fact, some specimens appear to be approaching crack arrest. Because of this, the importance of self-loading from corrosion product wedging as a significant driving force for crack propagation in overaged materials is questioned. (Self-loading is clearly a significant factor for underaged materials, however.) Also, K_{Isc} values for -T7X materials are less than the original estimates: 9-15 MPa \sqrt{m} for 7050 and 10-14 MPa \sqrt{m} for 7049. K_{Isc} for high toughness production 7475-T73 plate is 33-35 MPa \sqrt{m} . (The higher values are for thicker plates.)

Crack length-time data were analyzed using a computer curve fitting program which minimized the effects of normal data scatter, and provided a clearer picture of material performance. Precracked specimen data are supported by the results of smooth specimen tests.

Transgranular stress corrosion cracking was observed in TL DCB specimens from all four alloys. This process is extremely slow ($\leq 2.5 \cdot 10^{-12}$ m/sec), and is characterized by a striated surface morphology.

FOREWORD

This is the second biennial report on marine atmospheric tests that were initiated under Contract NAS8-30890 for the George C. Marshall Space Flight Center of the National Aeronautics and Space Administration. The work was administered under the technical direction of the Propulsion and Vehicle Engineering Laboratory, Materials Division of the George C. Marshall Space Flight Center, with T. S. Humphries serving as Contracting Officer's Representative.

All investigations on alloys 7075-T7351, 7475-T7351, and 7050-T73651 were sponsored by NASA; costs incurred for the concurrent evaluation of alloy 7049 and for the inclusion of 7075-T651 and 7075-T7651 control materials were supported by KACC.

Although the investigation conducted under this contract was completed with the writing of the final report (October 15, 1976), marine atmospheric exposure tests are being continued for at least six years, with results being reported every two years.

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INTRODUCTION

The overaged alloy 7075-T73 was the first of the stress-corrosion (SC) resistant 7000-series aluminum alloys to be used in aerospace applications. Although this alloy offers excellent stress-corrosion resistance (SCR) in the short-transverse orientation, its use can result in weight penalties because of its lower strength compared to 7075-T6, 7178-T6, and 7079-T6. This situation provided the impetus for the development of alloys designed to have good SCR in combination with high strength (Refs 1, 2).

Measurements of SC susceptibility have traditionally been given in terms of time-to-failure of "smooth" specimens which have been loaded at various stresses and then exposed to an appropriate corrosive environment. In recent years, SC tests utilizing precracked specimens have received attention because they can provide a means of determining quantitative crack growth rate information.

The objective of this 1975 program was to compare the SC behavior of the newer SC resistant, high-strength alloys (7475-T7351, 7050-T73561 and 7049-T7351) with that of the established alloy 7075-T7351. The previously reported laboratory tests and preliminary marine atmospheric results (Ref 3) on smooth and precracked specimens from 32- and 76-mm thick plates showed that for a given strength level, alloys 7050-T7X and 7049-T7X have superior short-transverse SCR to 7075-T7X. At typical strength levels above the minimum of 7075-T6, for example, the SCR of these alloys is better than that of 7075-T76, and approaches that of 7075-T73.

This report updates the marine atmospheric test data, which have now been accumulated for up to 54 months exposure.

EXPERIMENTAL

Materials

Plates 32 and 76-mm (1.25 and 3.0 in.) thick having compositions shown in Table I were fabricated from 305-mm (12-in.) thick DC-cast ingots. For comparative purposes, all the new alloys had the same purity level (0.06% Si, 0.10% Fe).

After heat treating and step-1 aging to the -T651 temper, the plates were step-2 aged by treatments selected on the basis of target tensile properties. The desired yield strength for "typical" 7075 was 34.5 MPa (5 ksi) above the minimum specified strength level for the particular plate thickness. Similarly, for 7050 and 7049, the desired typical yield strength was 27.5 MPa (4 ksi) above the minimum value. The electrical conductivities, long-transverse tensile properties, and fracture toughness of the plates are given in Table II. Properties for 7075-T651 and 7075-T7651 are also included since they were used as "control" materials in the SC tests. In all cases, the strengths of the overaged 7049 and 7050 plates were substantially greater than those of the corresponding 7075-T7351 materials, and in most instances approached the intermediate 7075-T7651 strength level. They were also equal to or greater than the minimum values specified for 7075-T651 (Ref 4).

In addition to these original materials, limited tests were conducted on samples of 38-mm and 89-mm 7475 plate having nominal fracture toughness levels. These materials, representing

standard Kaiser Ravenswood production lots, were added in 1977 to provide a comparison with the relatively low toughness 7475 plate produced for this program. The 38-mm lot was tested in the -T6 -T76 and -T73 tempers. The 89-mm lot was tested in the -T7351 temper. Mechanical properties of these plates are shown in Table III.

Stress Corrosion Tests

The SC tests were conducted in a coastal marine environment near Daytona Beach, Florida, with both smooth and precracked specimens. The smooth specimens were 3.175-mm diameter tensile rounds, stressed in window frame jigs. The -T73 temper materials were exposed at four stress levels between 172 and 379 MPa (25, 35, 45, and 55 ksi). The 7075-T651 and 7075-T7651 materials were stressed at 34 to 172 MPa (5, 15, and 25 ksi) and 172 to 310 MPa (25, 35 and 45 ksi), respectively.

Crack-line loaded double cantilever beam (DCB) specimens were used for the crack growth tests. This specimen has been widely used for in-service evaluations in which crack growth behavior is studied under constant-deflection (decreasing stress intensity) conditions. The DCB test specimens were machined from the center of the plate thickness and oriented so that cracking would occur in either the short-transverse or long-transverse plane and propagate in the rolling direction (S-L and T-L orientations, respectively).

Most of the DCB specimens were 25-mm wide by 25-mm high by 125-mm long, and were precracked by mechanical "pop-in". In addition, a few 75-mm high S-L specimens were tested, and a number of fatigue-precracked S-L specimens from the thinner plates were also included. The DCB specimens had chevron notches

and were sidegrooved (5% per side) to help provide a straight crack front, suppress formation of shear lips, and keep the crack growing in the proper plane (Refs 5 and 6).

The DCB specimens from the nominal toughness 7475 plate were modified to allow for the higher expected stress intensities. Specimen beams were the maximum height allowed by the plate thickness. Specimens from the 38-mm plate were 19 mm wide and specimens from the 89-mm plate were 25 mm wide. All of these specimens had 10% side grooves on each side, and were precracked by fatigue.

Prior to precracking and testing, the specimens were etch-cleaned in 5% NaOH solution at 180°C, desmutted in cold 50% HNO₃, and rinsed in hot deionized water. Most of the specimens were precracked by turning a pair of stainless steel bolts into the machined slot at the end of the specimen. The cracks were propagated about 2-3 mm beyond the end of the chevron; total crack lengths were about 28 mm as measured from the load point. Deflections were measured with a clip-in strain gage at the integral knife edges, and crack lengths were measured optically at the specimen edges with the help of a binocular microscope.

Stress intensities were calculated from the relation (Ref 5)

$$K = \frac{\delta E h^{3/2} \phi [3(a + 0.6h)^2 + h^2]^{1/2}}{4[a + 0.6h]^3 + h^2 a} \quad (1)$$

where a is the crack length; h is the specimen beam height; δ is the deflection at the load point (determined by applying an empirical correction factor to the end measurements); E is the modulus of elasticity; and ϕ , a correction factor for side grooves, was assumed to be equal to $(b/b_n)^{0.5}$, where b and b_n are the full and reduced sections, respectively.

Specimens that were fatigue precracked were bolt loaded to about 90% of K_{Ia} , the stress intensity for mechanical arrest, which was determined from the specimens precracked by mechanical pop-in. All the specimens with pop-in precracks were tested at an initial stress intensity of K_{Ia} .

After precracking and loading, the specimens were bolted to test frames and shipped by air freight to Daytona Beach. There they were suspended bolt-end down to keep runoff from the stainless steel bolts out of the cracks. Initial crack length measurements were made at approximately 1 day, 2 days, 4 days, 1 week, 2 weeks, 1 month, 2 months, 4 months, 6 months, and 1 year. (Subsequent measurements have been made annually.) The average of the crack lengths measured at each edge was used in the calculation of stress intensity (Eq. 1) and crack growth rate.

RESULTS

Smooth Specimen Tests

Results of short transverse smooth specimen tests of 32-mm and 76-mm plate are shown in Tables IV and V, respectively. The thinner plates had lower stress corrosion resistance than the thicker plate. For example, in 32-mm plate, failures have occurred in 7075-T7351 and 7050-T73651 at stress levels of 310 MPa (45 ksi) and above, and in 7475-T7351 and 7049-T7351 at stress levels of 241 MPa (35 ksi) and above during the 54-month exposure. The 32-mm 7075-T651 specimens failed at 34 MPa (5 ksi) at 34 and 48 months, and 7075-T7651 specimens failed at 172 MPa (25 ksi) within 2.3 months.

In 76-mm plate, single failures occurred in 7050-T73651 and 7049-T7351 specimens at 379 MPa (55 ksi). Failures occurred in the 76-mm 7075-T651 plate at 103 MPa (15 ksi) and above in 0.4 month or less, and in the -T7651 at 241 MPa (35 ksi) and above in 48 months or less.

Failures occurred in long transverse specimens from 76-mm 7075-T651 plate only at 379 MPa (55 ksi) stress. See Table VI.

Precracked Specimen Tests

Data Analysis

Data for the precracked specimen tests are expressed in the form of crack length vs time and crack growth rate vs stress intensity (V-K) plots. Computerized curve fitting techniques have been applied to the crack length/time data, and the slope (da/dt) of the resulting curve has been used to generate the V-K plots. This technique has reduced the effect of scatter in the crack growth rate data and thus provides a clearer picture of crack growth rate/stress intensity behavior.*

Figures 1 and 2 show the crack length/time and the crack growth rate/stress intensity plots for the 25-mm SL DCB specimens from the 32-mm 7075 plates. The actual data points were determined from da/dt for each measurement interval, but the V-K curve was generated by the curve fitting process described above. Note

*It has been observed that visual measurement of crack length on the sides of a DCB specimen tends to underestimate the true crack length by approximately 10% (Table VII). Thus, no matter how effective the data evaluation procedure, there is a natural bias because of the crack measurement procedure.

the near-idealized behavior of the -T7351 and -T7651 specimens. The -T651 specimen, however, shows no indication of an approach to a threshold stress intensity*. (This specimen was removed from exposure after two years when the crack grew out of plane. The last two data points are probably invalid.)

These curves are presented here as an example of data analysis procedure and to show the relative resistance to stress corrosion crack propagation of the three 7075 tempers. The remaining computer generated curves are presented in the appendix.

Material Comparisons

Figure 3 shows a composite of the V-K curves for SL specimens from the 32-mm and 76-mm 7075 plate in all three tempers. Neither the 32-mm or the 76-mm -T651 curve shows any indication of a threshold value. These curve shapes are indicative of specimen self-loading as a result of corrosion product wedging (Ref 7). Visible self-loading was in fact noted in the specimens from the 76-mm plate after two years exposure. Estimates of threshold stress intensity can be obtained from the other curves. The 76-mm 7075-T7351, for example, has a threshold above $23 \text{ MPa}\sqrt{\text{m}}$. The 76-mm -T7651 and the 32-mm -T7351 have similar thresholds of about 16-18 $\text{MPa}\sqrt{\text{m}}$. The 76-mm -T7651 and -T7351 materials also appear to be approaching true crack arrest.

Figure 4 is a composite of the V-K curves for the 7475, 7050 and 7049 plates. While threshold stress intensities for some of the plates are not well defined, there is a consistent trend towards decreasing crack growth rates at stress intensities

*Often taken to be the stress intensity at which the crack growth rate decreases to 10^{-10} m/sec or less.

below 15 MPa \sqrt{m} . It is not clear whether (or to what extent) self-loading is influencing the crack growth rates at this point. The data for the 76-mm 7475 plate, however, indicate a well-defined threshold value of about 29 MPa \sqrt{m} . This specimen is also approaching crack arrest at about 25 MPa \sqrt{m} .

Fatigue Precracked Specimens

Figure 5 shows the results of tests on fatigue precracked specimens from the 32-mm plates. The curves for the 7050-T73 and 7049-T73 are similar to those obtained from the "pop-in" pre-crack specimens. However, initial crack growth rates in the fatigue precracked specimens from the 7075-T7351 and 7475-T7351 plates were much lower than in "pop-in" precracked specimens. The crack growth rate in these specimens has increased to about the same values as in the "pop-in" specimens after four years exposure. This behavior was originally attributed to self-loading, but it may, in fact, be an initiation stage where crack growth is slow while the crack front makes the transition from a transgranular fatigue crack to an intergranular stress corrosion crack (Ref 8).

76-mm Specimens

V-K plots for the 76-mm high specimens taken from the 76-mm plates are shown in Figure 6. The curves for the 7049, 7050 and 7075 plates are similar to those obtained with 25-mm specimens, except that the 76-mm 7049 and 7050 specimens have a well-defined threshold value whereas the 25-mm specimens did not. This appears to support the original observation that self-loading effects are more apparent in thinner specimens. In 7475, the 76-mm specimen, unlike the 25-mm specimen, shows an initiation stage similar to that observed in the fatigue precracked specimen. There is no obvious explanation for this behavior.

TL Specimens

V-K curves are not presented for TL orientation specimens. While some transgranular stress corrosion crack growth did occur in the TL orientation, the major cracks occurred in the SL orientation and took the shape of the plastic zone (Ref 9). Such cracks cannot be measured on the edges of the specimens. Furthermore, stress intensity values calculated for these cracks would not be valid. Total crack growth measured on the fracture surfaces of specimens broken open after four years exposure is shown in Table VIII. Some comparisons can be made on this basis. For example, specimens from the 32-mm plates had more crack growth than the 76-mm plates and specimens from the 7050 and 7049 plates had more crack growth than the 7075 and 7475 plates. These observations are consistent with SL specimen behavior.

Figures 7 through 13 show light and SEM fractographs of the TL specimens. All of the TL fractures examined* showed distinct brittle transgranular fracture. These transgranular cracks initiated on the surfaces of short-transverse, intergranular stress corrosion cracks described previously and then propagated laterally to connect the ligaments. There was also some crack propagation in the longitudinal direction (both forward and backward). The transgranular crack growth rate, as estimated from measurements of the crack sizes, is not greater than 2.5×10^{-11} m/sec, i.e. this rate is less than the K_{Isc} defined rate.

The transgranular fractures had well-defined "river marks" and striations showing the direction of crack propagation. There is little doubt that these cracks were caused by stress corrosion. Such stress corrosion cracks have been observed in other materials (Ref 10), but mechanisms and reasons for the striations are not understood.

*There were no TL specimens from the 32-mm 7075-T7351 or the nominal toughness 7475 plates.

Nominal Toughness 7475 Plate

As previously noted, limited tests were conducted on production 7475 plates having greater fracture toughness than the material fabricated for this contract. Crack length/time and V-K curves for SL specimens that have been exposed to marine atmosphere about 2-1/2 years are shown in Figures 14 and 15, respectively. The nominal toughness -T73 plates, both 38 and 89 mm, initially had higher crack growth rates (at higher initial stress intensities) than the lower toughness 7475-T73. However these rates decreased rapidly, resulting in significantly higher threshold stress intensity values for the higher toughness materials.

The -T76 specimens (38 mm only) had similar high initial crack growth rates at high stress intensities, but a plateau is apparent between 16 and 33 MPa \sqrt{m} at about 3×10^{-10} m/sec. This behavior is similar to that of the 32 mm 7049 and 7050 plates. The -T6 specimens (38 mm only) had high initial crack growth rates similar to that of 7075-T6, but unlike 7075-T6, they show no obvious sign of self-loading and appear to be approaching a threshold stress intensity below 5 MPa \sqrt{m} .

Even though the higher initial stress intensity may produce higher initial crack growth rates, the threshold stress intensity values are at least as good as, or better than, those for lower toughness material. The absence (or reduced effect) of self-loading in 7475 plate, even in the -T6 temper, is also worth noting.

Threshold Stress Intensity (K_{ISCC}) Estimates

In most cases K_{ISCC} can be read directly from the V-K plots or estimated by extrapolation of curves that show a distinct downturn.

(Note that some curves even appear to extrapolate to true crack arrest.) In other cases, the crack growth rate appears to be decreasing at a more or less steady rate over a range of stress intensities with no distinct downturn. In such cases (32-mm 7049 and 7050, for example), K_{Isc} can only be estimated to be below the lower limit of the curve. It is not clear at this time whether self-loading is responsible for the latter behavior. If it is, it would seem that 7075 and 7475 should show similar behavior.

Estimates of threshold stress intensities determined from these considerations are shown in Table IX. Note that these values, which assume that self-loading is not a factor, are much lower than those previously reported after two years exposure (Ref 11). Previous values were estimated under the assumption that crack growth after the first six months exposure was primarily the result of self-loading. The overaged 7075 and 7475 plates have the highest K_{Isc} values of about 15-19 and 24-31 $\text{MPa}\sqrt{\text{m}}$ for 32 and 76-mm plate, respectively. Corresponding threshold values for the 7050 plates are 9 and 15 $\text{MPa}\sqrt{\text{m}}$, and for 7049 plates, 10 and 14 $\text{MPa}\sqrt{\text{m}}$. The nominal toughness 7475-T7351 plates have thresholds of about 33 and 35 $\text{MPa}\sqrt{\text{m}}$.

Except for the 7475 plate, the K_{Isc} estimates obtained from 25-mm specimens are about the same as those obtained from 76-mm specimens. The difference in the 7475 is the result of the unusual behavior of the 76-mm specimen noted earlier. Another parameter sometimes used for comparison of materials and determination of inspection intervals in critical structures is the plateau (stage II) crack velocity. Estimates of plateau velocities are also given in Table IX. Note that some plateaus actually occur below the arbitrary 1×10^{-10} m/sec crack growth rate used to determine K_{Isc} .

DISCUSSION

The original plate materials were fabricated in 1975 especially for this study because (1) suitable standard production plate was not available in all four alloys at that time, and (2) it seemed desirable to produce all four materials by the same practice. Target strength levels representing typical mechanical properties were used to determine the optimum heat treatment practices for all four materials. While the strengths and electrical conductivities of all materials were satisfactory, the fracture toughness of the 7475 plate was low. (For this reason, the nominal toughness 7475 production plate materials were later added to the study.) The superior stress corrosion crack propagation resistance of the production 7475 plates, compared to the project 7475, is noteworthy. We might suspect therefore that the other project materials also have below average resistance to stress corrosion crack propagation. However, there is also a possibility that a material with higher toughness is inherently more resistant to stress corrosion (Ref 12). Nevertheless, the K_{Isc} values can be used for comparing the four project materials; but they should not be considered as necessarily representing typical values for these products.

The question of self-loading as a result of corrosion product wedging remains to be settled. If self-loading has been the primary driving force for crack propagation after six months exposure (as postulated in the two-year report), then the current estimates for K_{Isc} are too low. However, now there are indications that self-loading has a minimal effect in the overaged temper materials. For example, specimens from 7075 and 7475, and in particular the nominal toughness 7475, show near ideal V-K curves with plateaus and a distinct decrease in crack growth rate at lower stress intensities indicating an approach

to crack arrest. We also note that crack growth rates calculated from actual increases in crack length between intervals ($\Delta a/\Delta t$) are quite variable. It is difficult to determine the true shape of the V-K curve from such data--the best visual fit is usually a straight line. Because the initial data are frequently more variable (perhaps because of initiation effects), the crack growth rate may seem to increase after some initial exposure period. This behavior can be interpreted as the result of self-loading.

There is no doubt, however, that self-loading can become a significant driving force for crack propagation in underaged and peak-aged materials (Ref 7), and it seems reasonable to assume that it can influence the behavior of overaged (more SC resistant) materials to some extent. Whether this invalidates estimates of threshold stress intensity remains to be determined by longer term tests.

SUMMARY AND CONCLUSIONS

After up to four years exposure to a marine atmosphere, DCB specimens from 7075-T7351 and 7475-T7351 plates have reached well-defined threshold stress intensity limits (K_{Isc}) and appear to be approaching crack arrest. K_{Isc} is 15 to 19 MPa \sqrt{m} for the 32-mm plates and 24 to 31 MPa \sqrt{m} for the 76-mm plates. Cracks in DCB's from overaged 7050 and 7049 plate materials are continuing to grow at near plateau rates at stress intensities below 13 MPa \sqrt{m} with only a slight indication of a downturn. It is not yet clear to what extent this behavior is affected by self-loading from corrosion product wedging.

STATUS

Marine atmosphere exposures of both smooth and precracked specimens will be continued to at least six years.

REFERENCES

1. J. V. Luhan and T. J. Summerson, "Development of 7049-T73 High-Strength, Stress-Corrosion Resistant Aluminum Alloy Forgings," Metals Engineering Quarterly, 10, No. 4, p. 35 (1970).
2. J. T. Staley and H. Y. Hunsicker, "Exploratory Development of High-Strength, Stress-Corrosion Resistant Aluminum Alloy for Use in Thick Section Applications," Technical Report, AFML-TR-70-256, November 1970.
3. R. C. Dorward and K. R. Hasse, "Flaw Growth of 7075, 7475, 7049 and 7050 Aluminum Alloy Plate in Stress Corrosion Environments, Final Report, Contract NAS8-30890," October 15, 1976.
4. Aluminum Standards and Data, The Aluminum Association, p. 110, 1976.
5. S. Mostovoy, P. B. Crosley, and E. J. Ripling, "Use of Crack-Line-Loaded Specimens for Measuring Plane Strain Fracture Toughness," Journal of Materials, 2, p. 661 (1967).
6. C. N. Freed and J. M. Krafft, "Effect of Side Grooving on Measurements of Plane Strain Fracture Toughness," Journal of Materials, 1, p. 770 (1966).
7. R. C. Dorward, K. R. Hasse and W. J. Helfrich, "Marine Atmospheric Stress Corrosion Tests on Precracked Specimens from High-Strength Aluminum Alloys: Effect of Corrosion Product Wedging," ASTM Journal of Testing and Evaluation, 6, p. 268 (1978).

REFERENCES (Cont'd)

8. R. C. Dorward and K. R. Hasse, "Incubation Effects in Pre-cracked Stress Corrosion Specimens from Al-Zn-Mg Alloy 7075," Corrosion Science, 19, p. 131 (1979).
9. R. C. Dorward and K. R. Hasse, "Long Transverse Stress Corrosion Cracking Behavior of Aluminum Alloy AA 7075," British Corrosion Journal, 13, p. 23, 1978.
10. Metals Handbook, Volume 9, "Fractography and Atlas of Fractographs," Eighth Edition, pp. 76, 77, 1974.
11. R. C. Dorward and K. R. Hasse, "Flaw Growth of 7075, 7475, 7050, and 7049 Aluminum Alloy Plate in Stress Corrosion Environments (Contract NAS8-30890): 2-Year Marine Atmosphere Results," CFT RR 78-16, June 22, 1978.
12. J. M. West, "Chemical Potential and Surface Energy in Stress-Corrosion Cracking," Metal Science Journal, 14, p. 534 (1980).

Table I. Chemical Compositions of the Plate Materials

Alloy	Plate* Thickness, mm	% By Weight**							
		Si	Fe	Cu	Mg	Cr	Zn	Ti	Zr
7075	32	0.14	0.16	1.45	2.49	0.20	5.78	0.03	0.00
7075	76	0.14	0.16	1.46	2.50	0.20	5.91	0.03	0.00
7475	32	0.06	0.10	1.57	2.23	0.20	5.96	0.02	0.00
7475	76	0.06	0.10	1.55	2.20	0.20	5.97	0.02	0.00
7050	32	0.06	0.10	2.10	2.08	0.00	6.00	0.02	0.12
7050	76	0.06	0.10	2.09	2.07	0.00	6.10	0.02	0.12
7049	32	0.06	0.10	1.53	2.48	0.14	7.60	0.02	0.00
7049	76	0.06	0.10	1.55	2.54	0.14	7.54	0.02	0.00

NOTE:

Cu, Mg and Zn based on atomic absorption analysis of the plates,
Si, Fe, Cr, Ti, and Zr based on Quantometer analysis of the melts and
plates.

* Both plates of each alloy were rolled from the same ingot.

** All other elements <0.005% each; <0.05% total.

Table II. Physical Properties of the Plate Materials

Material *	Plate Thickness (mm)	Electrical Conductivity (% IACS)	Strength (MPa)		Elongation (% in 2 in.)	Fracture Toughness (MPa√m)	
			UTS	YS		L-T	S-L
7075-T651	32	33.2	584	522	10.7	25.1	24.2
7075-T651	76	34.0	559	500	7.7	22.4	19.6
7075-T7651	32	38.4	544	489	10.2	25.2	23.1
7075-T7651	76	39.5	521	460	7.7	22.0	21.3
7075-T7351	32	41.6	498	429	10.5	26.7	24.3
7075-T7351	76	42.1	464	382	9.0	24.8	23.5
7475-T7351	32	43.4	495	420	11.7	31.7	26.7
7475-T7351	76	44.8	470	385	10.0	30.5	29.7
7050-T73651	32	41.9	537	477	11.8	31.2	27.3
7050-T73651	76	43.2	502	429	8.8	29.2	27.9
7049-T7351	32	42.5	520	461	11.0	31.2	27.8
7049-T7351	76	41.7	525	450	9.8	27.2	27.6

Notes: Tensile properties and fracture toughness values are averages for triplicate specimens.

Tensile properties are for long-transverse direction (YS is 0.2% offset).

*Overaging Time at 166°C (330°F)

	7075-T7651	7075-T7351	7475-T7351	7050-T73651	7049-T7351
32mm	9	27	26	23	23
76mm	15	48	32	30	21

Table III. Mechanical Properties and Chemical Composition
of Nominal Toughness 7475 Plate

Mechanical Properties of Test Plates
(Duplicate Long Transverse Tensiles)

<u>Thickness</u> <u>mm</u>	<u>Temper</u>	<u>TS, MPa</u>	<u>YS, MPa</u>	<u>Elongation</u> <u>8 in 2 in.</u>
38	-T6	570	510	13
38	-T76	516	452	13
38	-T73	464	386	14
89	-T7351	470	393	14.5

Fracture Toughness of Test Plate

<u>Thickness</u> <u>mm</u>	<u>Temper</u>	<u>K_{IC}, MPa√m</u>		
		<u>S-L</u>	<u>T-L</u>	<u>L-T</u>
89	-T7351	48.0 *	55.5	69.9 *

*K_{IQ}

Chemical Composition, Wt % (Quantometer)

	<u>Si</u>	<u>Fe</u>	<u>Cu</u>	<u>Mn</u>	<u>Mg</u>	<u>Cr</u>	<u>Zn</u>	<u>Ti</u>
38 mm	0.050	0.069	1.26	0.004	1.95	0.19	5.31	0.013
89 mm	0.050	0.068	1.30	0.003	1.96	0.21	5.36	0.012

Table IV. Summary of Marine Atmosphere Short-Transverse Stress Corrosion Test Results for Smooth Specimens from 32-mm Plates--54 Months Exposure

Applied Stress, MPa(ksi)	Alloy/Temper					
	7075					
	-T651	-T7651	-T7351(T)	7475-T7351(T)	7050-T73651(T)	7049-T7351(T)
	[522] [*]	[489]	[429]	[420]	[477]	[462]
34 (5)	2/3 (34.2, 48 mo)	-	-	-	-	-
103 (15)	3/3 (.2, 9, 15 mo)	-	-	-	-	-
172 (25)	3/3 (.1-.2 mo)	3/3 (.9-2.3 mo)	OK	OK	OK	OK
241 (35)	-	3/3 (.4-1.2 mo)	OK	1/3 (48 mo)	OK	3/3 (16,26,44 mo)
310 (45)	-	3/3 (.1-.4 mo)	3/3 (11,22,25 mo)	1/3 (48 mo)	3/3 (all 9 mo)	3/3 (9,9,32 mo)
379 (55)	-	-	3/3 (11,15,31 mo)	2/3 (40,48 mo)	3/3 (3.4,5,11 mo)	3/3 (all 9 mo)

NOTES: Results are listed as number specimens failed/number tested.

OK indicates 3 specimens survived 54-month exposure.

Specimen: 3.175mm diameter tensile type.

*Numbers in brackets are LT yield strengths (MPa). Minimum yield strengths for 32mm 7075-T651 and 7075-T7351 are 462 and 393 MPa, respectively.

Table V. Summary of Marine Atmosphere Short-Transverse
SCR Results for Smooth Specimens from 76mm
Plates--54 Months Exposure

Applied Stress, MPa (ksi)	Alloy/Temper					
	7075		-T7351 (T)	7475-T7351 (T)	7050-T73651 (T)	7049-T7351 (T)
	-T651	-T7651				
	[500] *	[460]	[382]	[384]	[429]	[449]
34 (5)	OK	-	-	-	-	-
103 (15)	3/3 (.1-.4 mo)	-	-	-	-	-
172 (25)	2/2 (.05 mo)	OK	OK	OK	OK	OK
241 (35)	-	3/3 (6,11,48 mo)	OK	OK	OK	OK
310 (45)	-	3/3 (.5-1.8 mo)	OK	OK	OK	OK
379 (55)	-	-	OK	OK	1/3 (19 mo)	1/3 (48 mo)

NOTES: Results are listed as number specimens failed/number tested.

OK indicates three specimens survived 54-month exposure.

Specimen: 3.175mm-diameter tensile type

*Numbers in brackets are LT yield strengths (MPa). Minimum yield strengths for 64-76mm
7075-T651 and 7075-T7351 are 420 and 338 MPa, respectively.

Table VI. Summary of Marine Atmosphere Long-Transverse
SCR Results for Smooth Specimens-54 Months
Exposure

Applied Stress, MPa (ksi)	Alloy/Temper					
	<u>-T651</u>	<u>7075 -T7651</u>	<u>-T7351 (T)</u>	<u>7475-T7351 (T)</u>	<u>7050-T73651 (T)</u>	<u>7049-T7351 (T)</u>
			<u>32mm Plate</u>			
310 (45)	-	-	OK	OK	OK	OK
379 (55)	OK	OK	OK	OK	OK	OK
			<u>76mm Plate</u>			
310 (45)	-	-	OK	OK	OK	OK
379 (55)	3/3 (3.4, 4.5 & 13 mo)	OK (345 MPa)	OK	OK	OK	OK

NOTES: Results are listed as number specimens failed/number tested.
OK indicates three specimens survived 54-month exposure.
Specimen: 3.175mm diameter tensile type.

Table VII. Comparison of Crack Length Measurements Obtained from Specimen Edges and Fracture Surface Measurements of S-L DCB Specimens

Edge measurements shown are the average of both sides; fracture surface measurements are the average of three to five values.

Material	Thick- ness, mm	Exposed 6.4 mo.				Exposed 53 mo.			
		Sides		Fracture		Sides		Fracture	
		\bar{a} , mm	K_I , MPa \sqrt{m}	\bar{a} , mm	K_I , MPa \sqrt{m}	\bar{a} , mm	K_I , MPa \sqrt{m}	\bar{a} , mm	K_I , MPa \sqrt{m}
7075-T7351	32	1.1	23.5	2.0	22.4	11.3	14.6	14.7	12.8
	76	1.1	24.5	0.5	25.3	2.9	22.4	4.1	21.2
7475-T7351	32	2.5	24.9	2.8	24.5	15.8	13.9	19.1	12.3
	76	1.8	28.7	0.9	30.0	4.1	25.6	7.2	22.1
7050-T73651	32	4.3	21.2	5.8	19.8	25.0	9.1	33.9	6.9
	76	2.2	26.5	2.8	25.0	17.9	13.2	NA	NA
7049-T7351	32	2.9	24.8	3.7	23.8	14.7	15.1	19.7	12.5
	76	2.5	25.0	3.9	23.3	15.7	14.1	24.5	10.3

\bar{a} = average crack length

Table VIII. Total Crack Growth in TL Specimens After
Four Years Exposure to Marine Atmosphere

Measurements were taken from fracture surfaces of broken
specimens.

	Crack Growth, mm	
	<u>32mm Plate</u>	<u>76mm Plate</u>
7075-T7351	1.8*	0.8
7475-T7351	2.3	2.0
7050-T73651	3.3	2.3
7049-T7351	3.6	1.8

* Measurement taken from sides of specimen not fracture surface.

Table IX. Estimates of Threshold Stress Intensity⁽¹⁾ (K_{Isc})
and Plateau Crack Growth Rates

SL DCB specimens were exposed to marine atmosphere at Daytona Beach, Florida for 53 months.

	32mm Plate ⁽²⁾		76mm Plate ⁽²⁾	
	K_{Isc} Ksi/ \sqrt{in} (MPa/ \sqrt{m})	Plateau da/dt , in/hr (m/sec)	K_{Isc} ⁽³⁾ Ksi/ \sqrt{in} (MPa/ \sqrt{m})	Plateau da/dt , in/hr (m/sec)
7075-T7351	17 (19)	1×10^{-5} (7×10^{-11})	22 (24) [21 (23)]	NP
7475-T7351 (low K_{IC})	14 (15)	1.5×10^{-5} (1×10^{-10})	28 (31) [21 (23)]	NP
7475-T7351 (Nominal K_{IC}) ⁽⁴⁾	30 (33)	NP	32 (35)	NP
7050-T73651	<8 (9)	5×10^{-5} (4×10^{-10})	14 (15) [15 (17)]	1×10^{-5} (7×10^{-11})
7049-T7351	<9 (10)	3×10^{-5} (2×10^{-10})	13 (14) [12 (13)]	1×10^{-5} (7×10^{-11})
7075-T651	<2.5 (3)	SL	<2.5 (3)	SL
7075-T7651	<5 (6)	4×10^{-5} (3×10^{-10})	14 (15)	2×10^{-5} (1.5×10^{-11})
7475-T651 ⁽⁴⁾	<3 (3)	5×10^{-4} (4×10^{-9})	NT	NT
7475-T7651 ⁽⁴⁾	<13 (14)	5×10^{-5} (4×10^{-10})	NT	NT

(1) Stress intensity at which da/dt becomes less than 1×10^{-10} m/sec.

(2) Nominal toughness 7475 plate was 38mm and 89mm thick.

(3) Values in brackets are from 76mm high specimens.

(4) Nominal toughness 7475 specimens have been exposed 28 months, all others 53 months.

NT - Not Tested;

NP - No Apparent Plateau, i.e., near vertical slope

SL - Specimen Self Loading; unable to estimate plateau velocity.

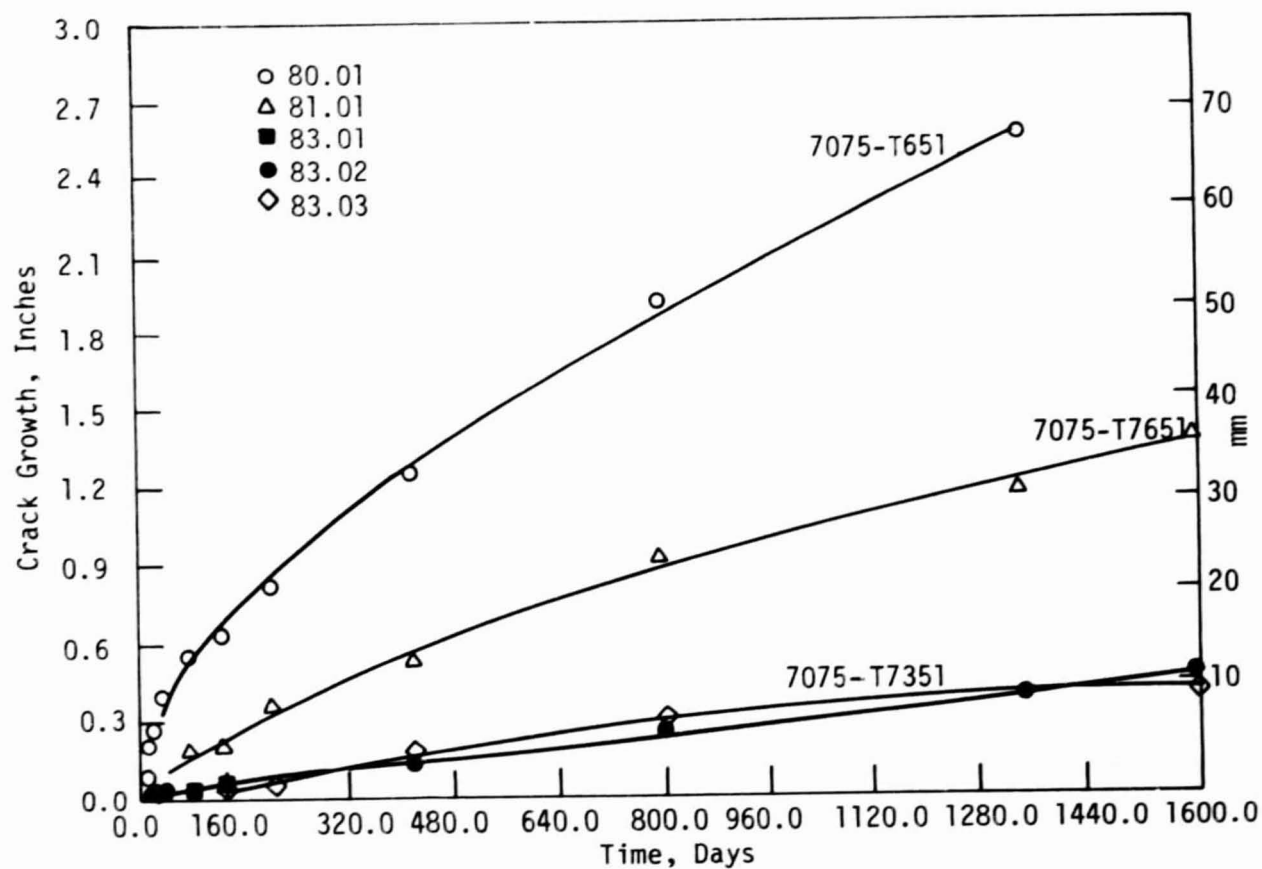


Figure 1. Stress Corrosion Crack Growth in DCB Specimens from 32-mm 7075 Plate

25 mm high SL specimens with pop-in precracks were exposed up to 54 months to marine atmosphere at Daytona Beach.

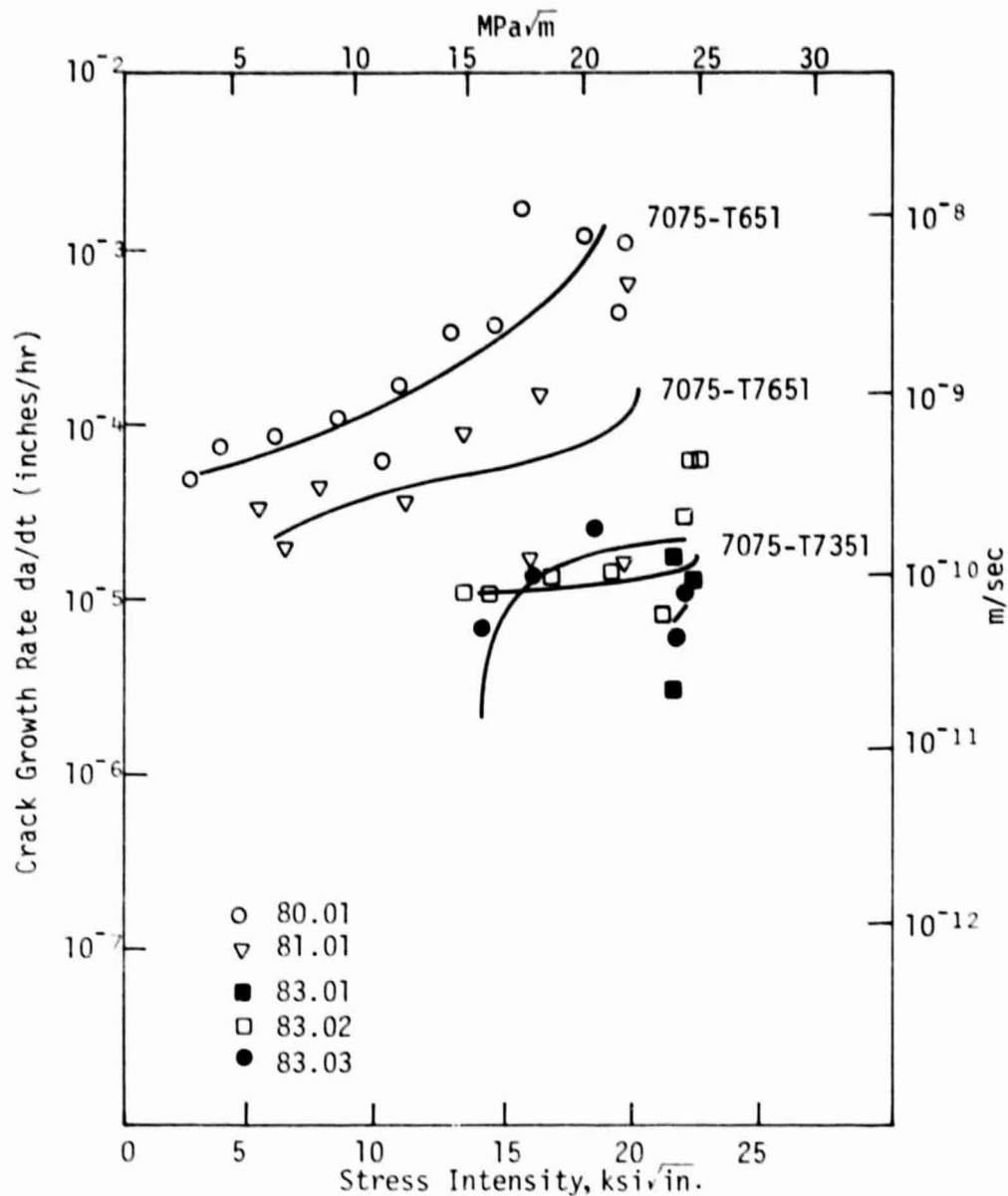


Figure 2. V-K Plots for DCB Specimens from 32-mm 7075 Plate

25-mm high SL specimens with pop-in precracks were exposed to marine atmosphere at Daytona Beach.

The crack in the -T6 specimen grew out of plane after 2 years exposure and the specimen was self-loading when it was terminated at 44 months.

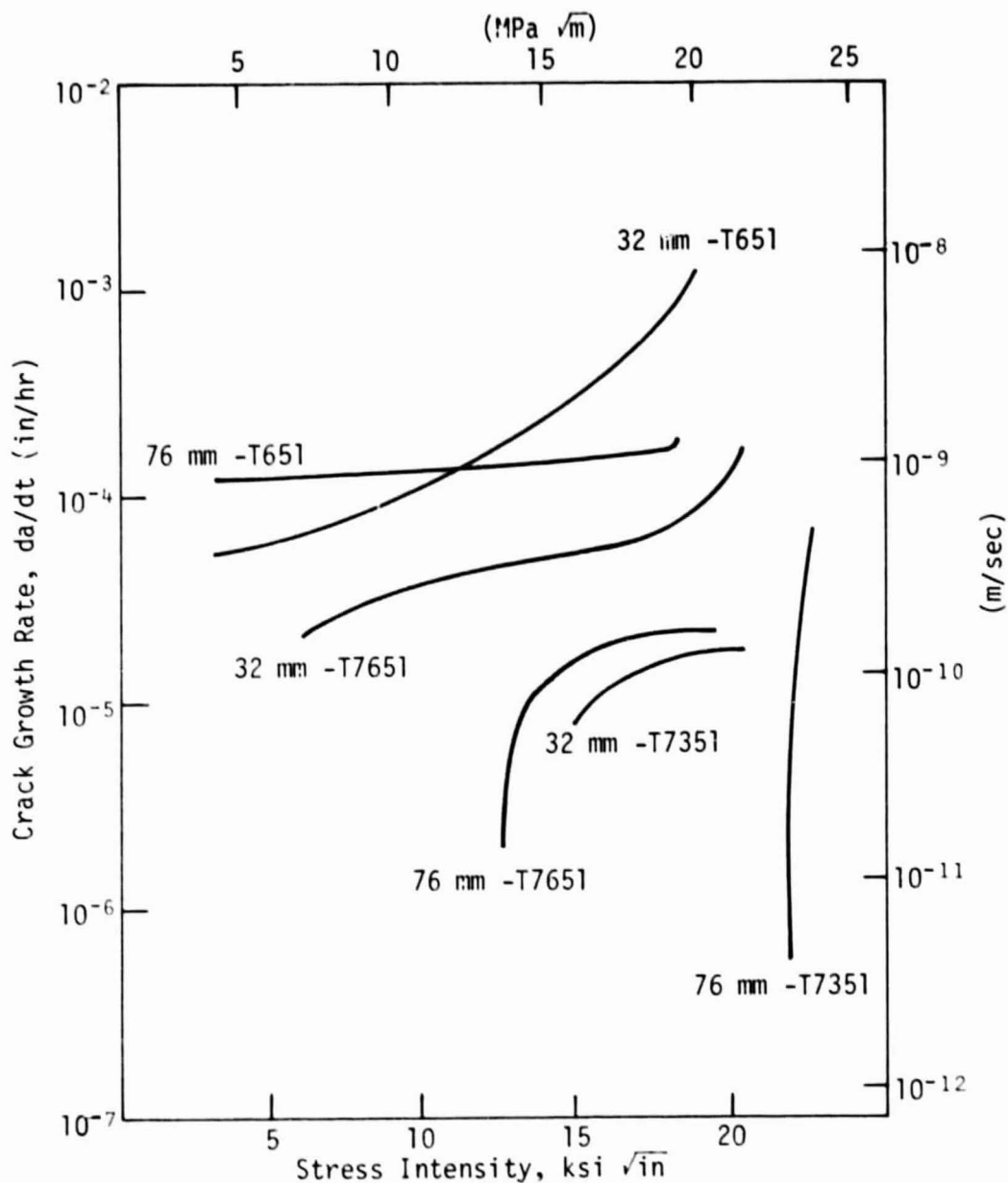


Figure 3. Composite V-K Curves for 32- and 76-mm 7075 Plate

25-mm high SL DCB specimens with pop-in precracks were exposed to marine atmosphere at Daytona Beach. Both -T651 specimens were visibly self-loading after two years exposure.

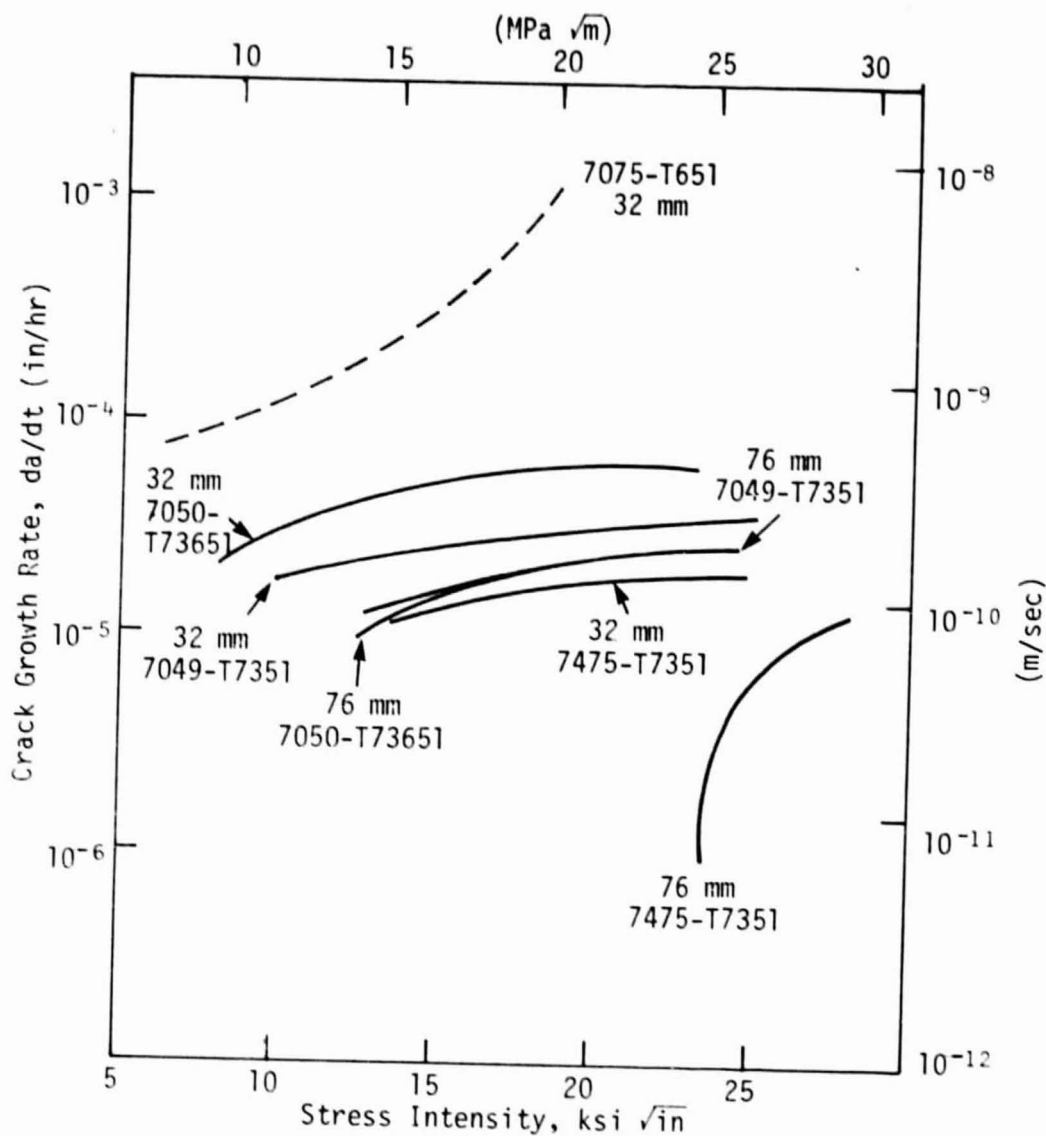


Figure 4. Composite V-K Curves for 32- and 76-mm
7049-T7351, 7050-T73651 and 7475-T7351 Plate

25-mm high SL DCB specimens with pop-in precracks were exposed to marine atmosphere at Daytona Beach for 52 months. The dashed line shows the 32-mm 7075-T651 curve for comparison.

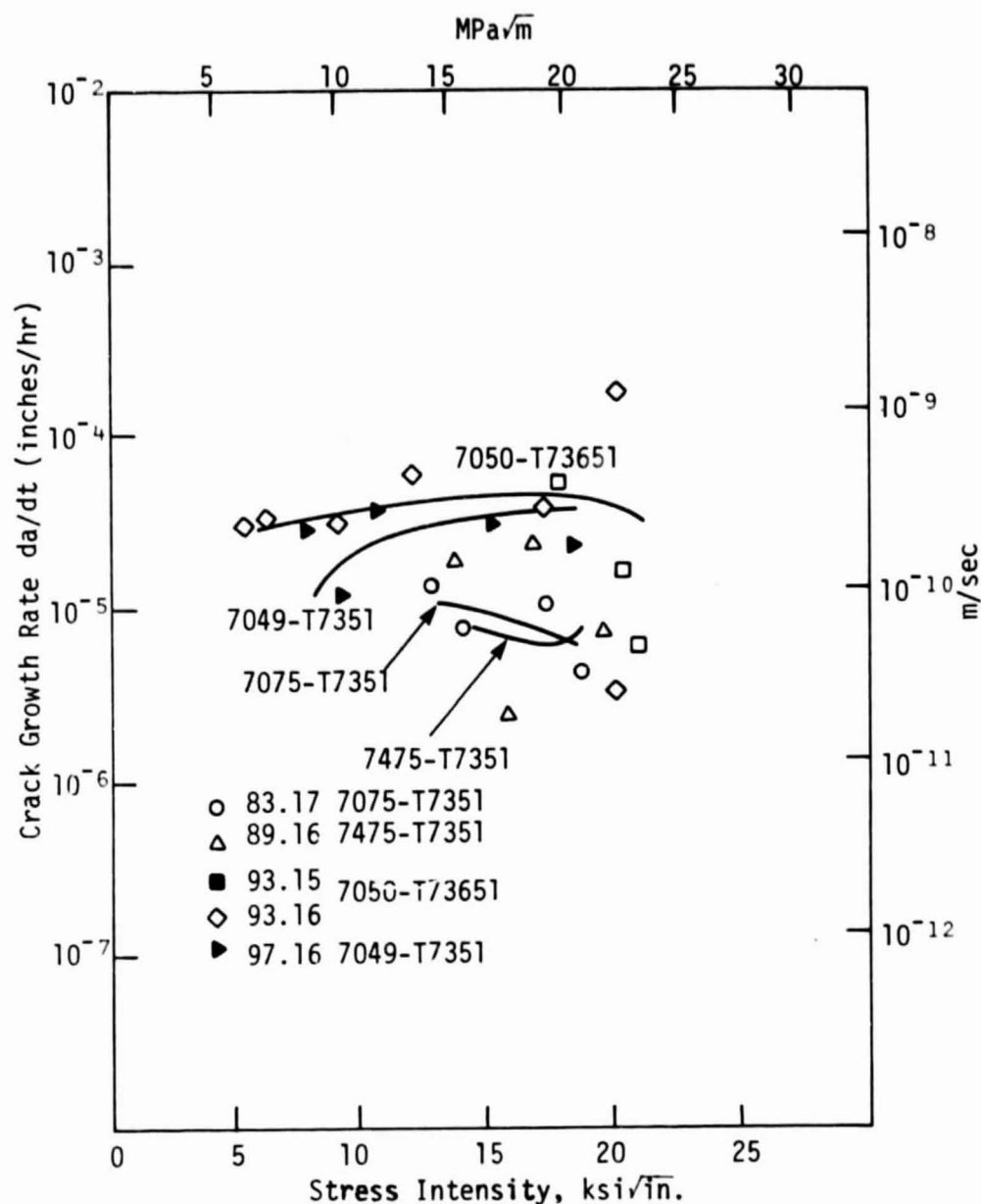


Figure 5. V-K Plots for Fatigue Precracked Specimens from 32-mm 7075-T7351, 7049-T7351, 7050-T7351 and 7475-T7351 Plate

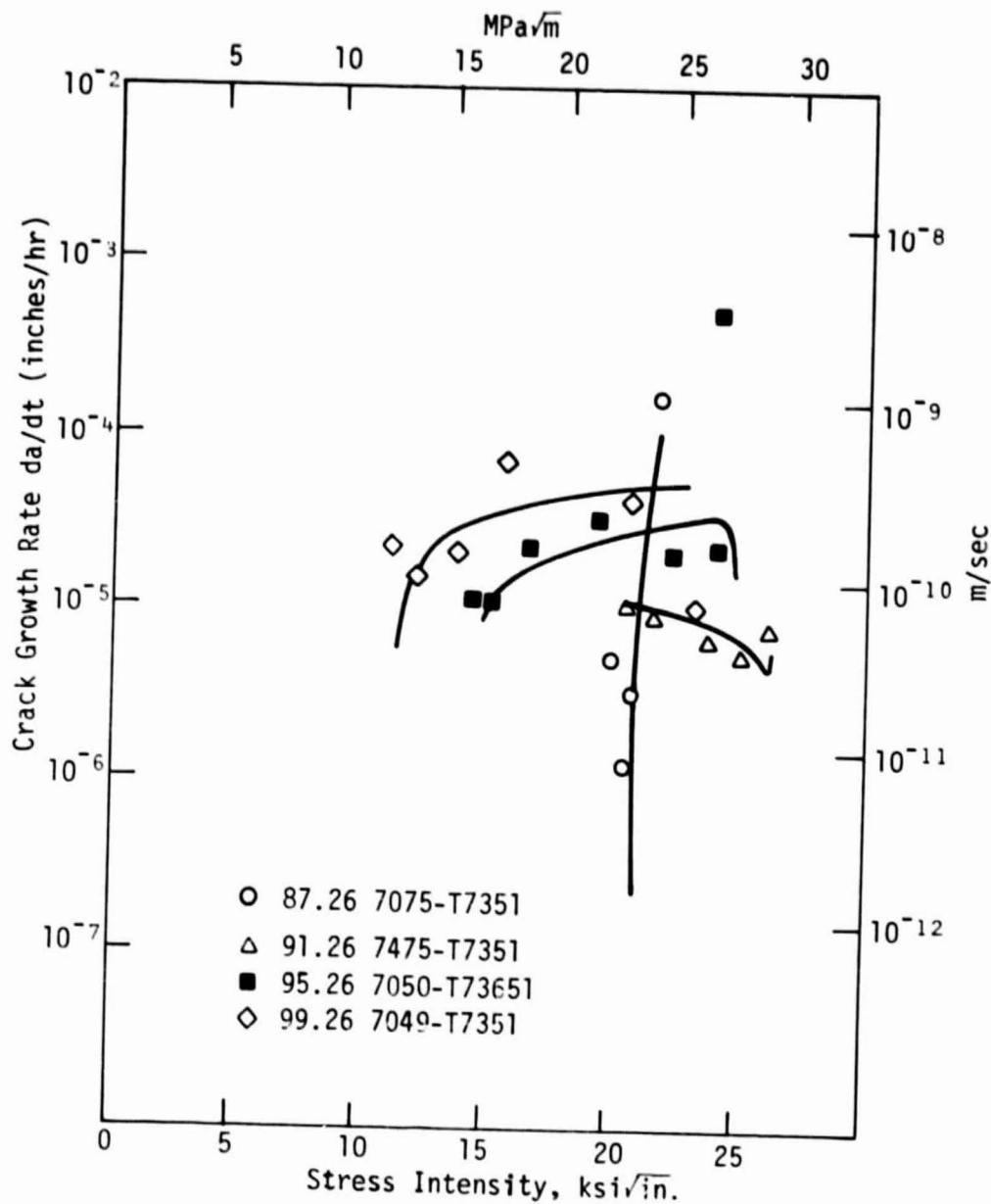
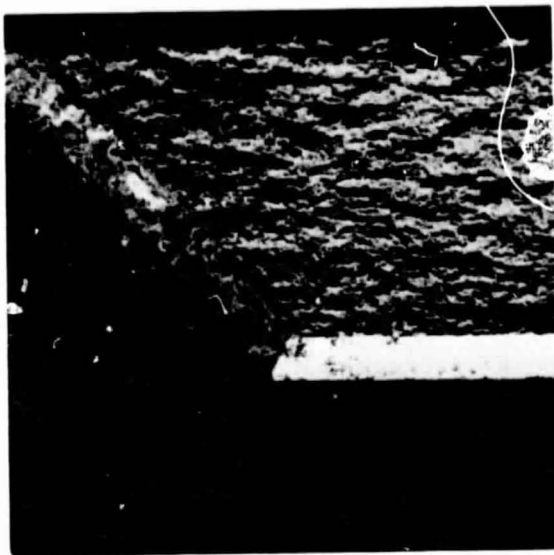


Figure 6. V-K Plots for 76-mm High Specimens from 76-mm Plates

SL specimens were exposed to marine atmosphere at Daytona Beach for 53 months. Note that the 7049, 7050 and 7075-T7351 plates have well-defined threshold stress intensities.



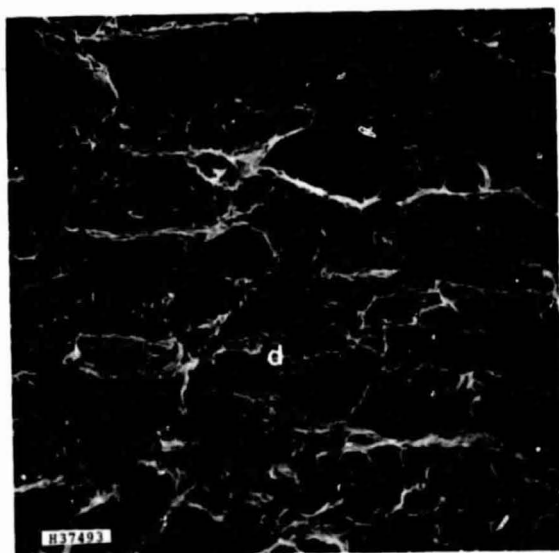
(a) —————→

4X



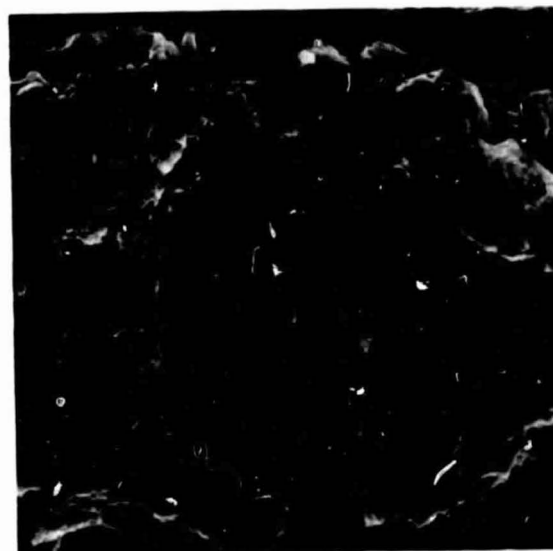
(b)

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(c)

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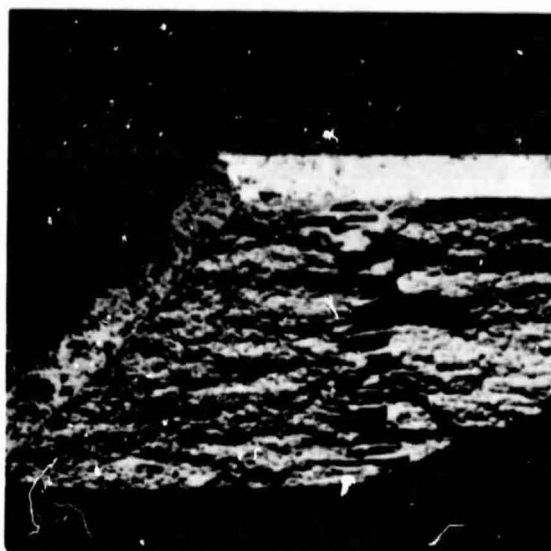
(d)

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Figure 7. Transgranular Stress Corrosion Cracking in a TL DCB Specimen from 76-mm 7075-T7351 Plate

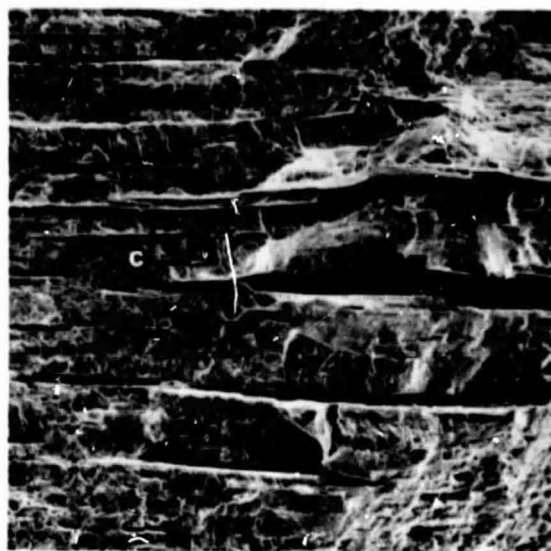
The 25-mm high specimen was exposed to marine atmosphere at Daytona Beach for 53 months. Arrow indicates intended direction of crack propagation.

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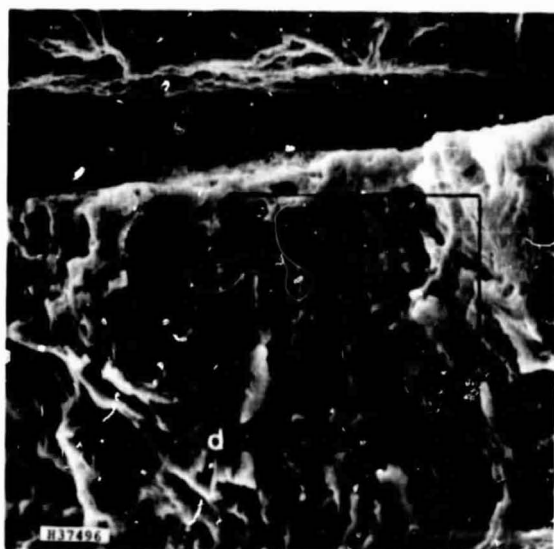
(a) —————→

4X



(b)

30X



(c)

500X

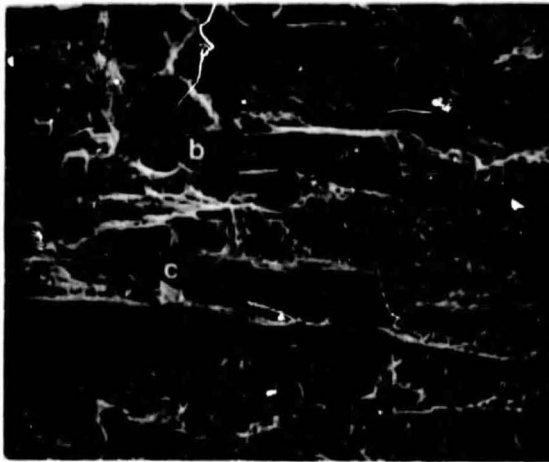


(d)

1000X

Figure 8. Transgranular Stress Corrosion Cracking in a TL DCB Specimen from 32-mm 7475-T7351 Plate

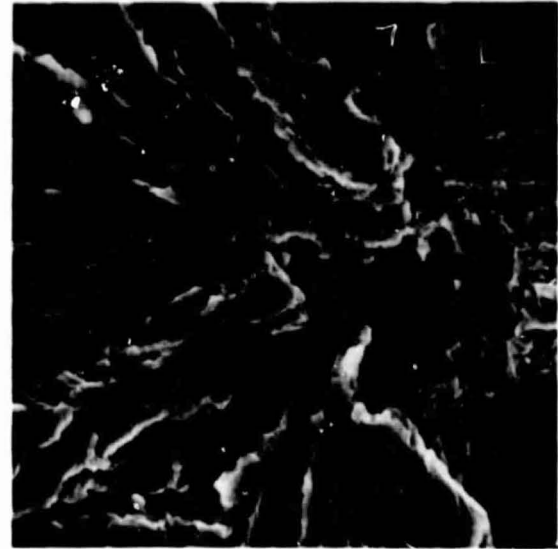
The 25-mm high specimen was exposed to marine atmosphere at Daytona Beach for 53 months. Arrow indicates intended direction of crack propagation.



(a)

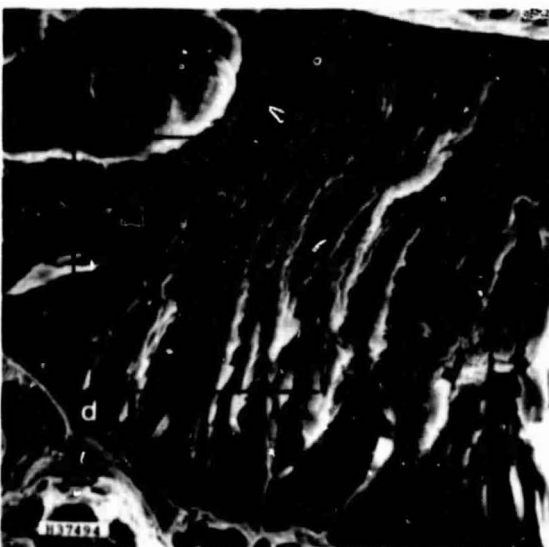


30X



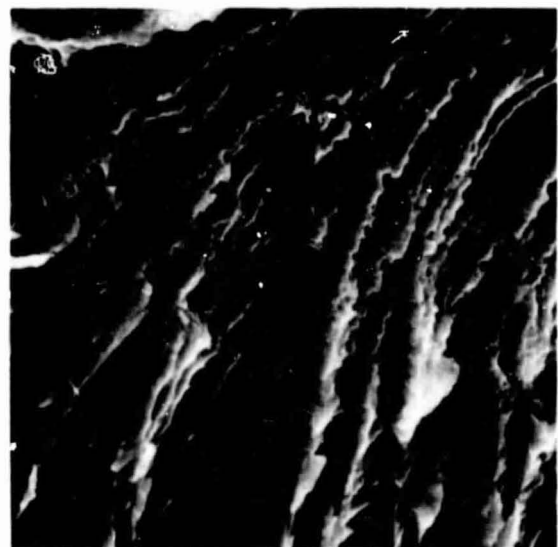
(b)

500X



(c)

500X



(d)

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Figure 9. Transgranular Stress Corrosion Cracking in a TL DCB Specimen from 76-mm 7475-T7351 Plate

The 25-mm high specimen was exposed to marine atmosphere at Daytona Beach for 53 months. Arrow indicates intended direction of crack propagation.



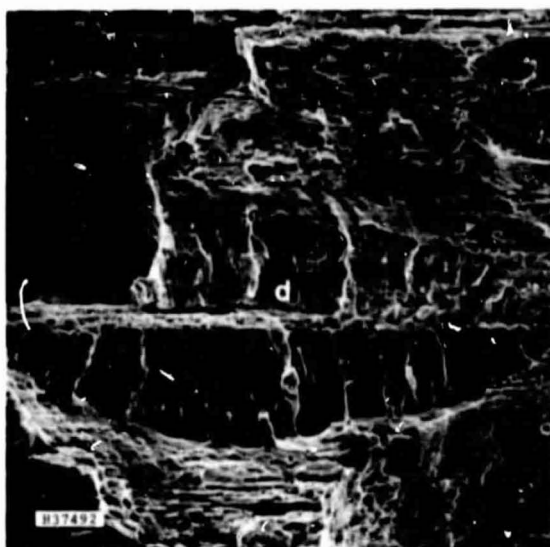
(a) —————▶

4X



(b)

30X



(c)

100X

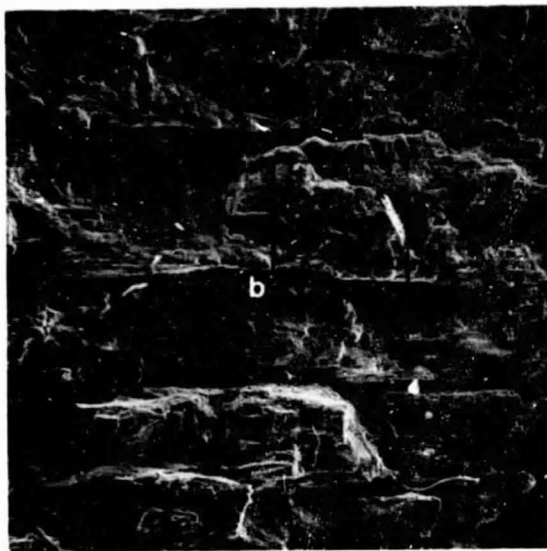


(d)

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Figure 10. Transgranular Stress Corrosion Cracking in a TL DCB Specimen from 32-mm 7050-T73651 Plate

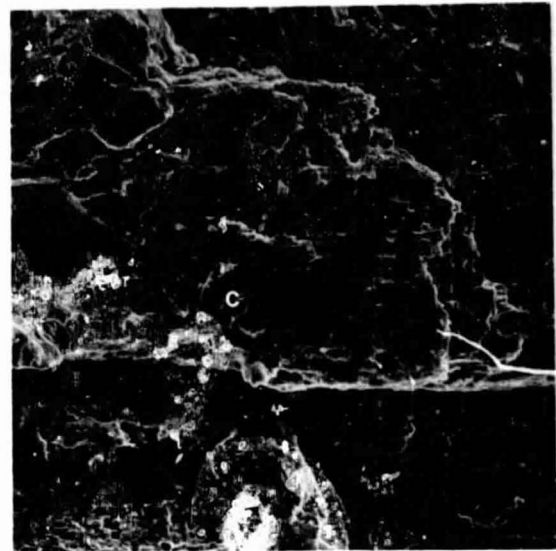
The 25-mm high specimen was exposed to marine atmosphere at Daytona Beach for 53 months. Arrow indicates intended direction of crack propagation.



(a)

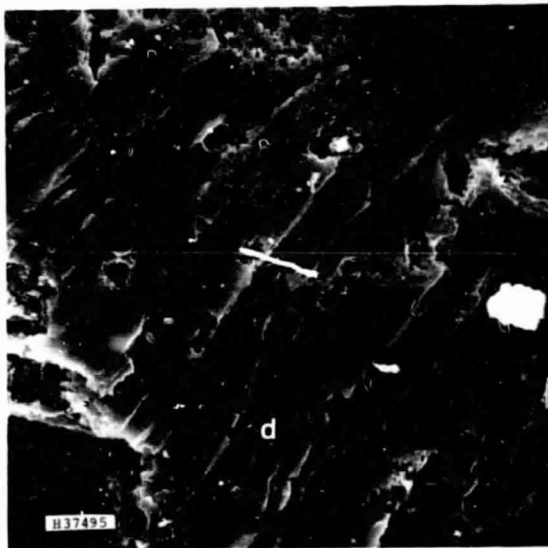


30X



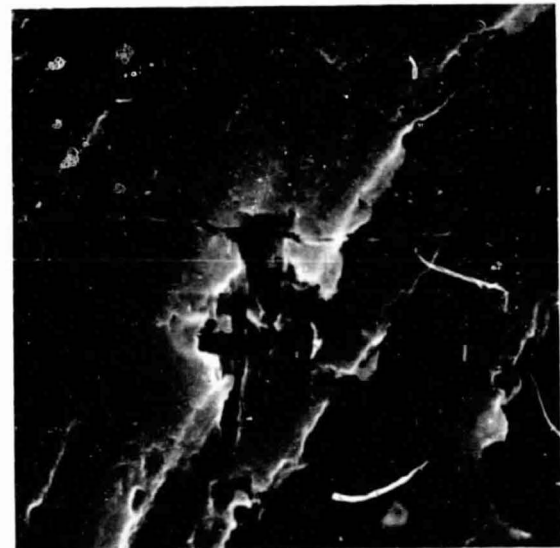
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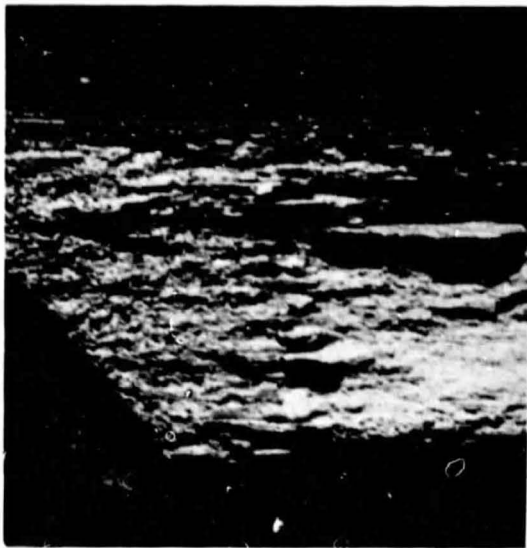


(d)

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Figure 11. Transgranular Stress Corrosion Cracking in a TL DCB Specimen from 76-mm 7050-T73651 Plate

The 25-mm high specimen was exposed to marine atmosphere at Daytona Beach for 53 months. Note the well defined river marks and striations. Arrow indicates intended direction of crack propagation.



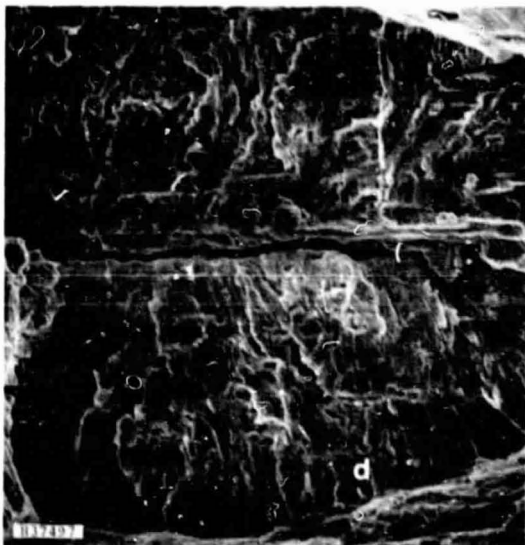
(a) —————>

4X



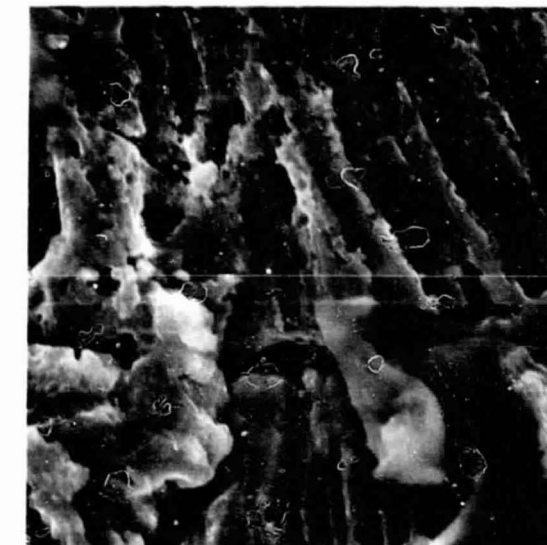
(b)

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(c)

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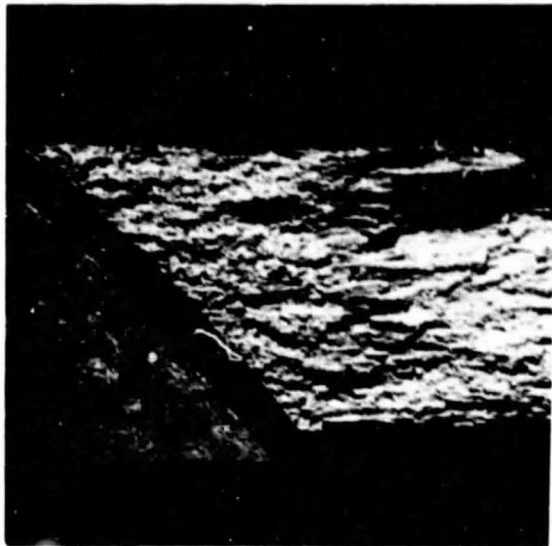
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Figure 12. Transgranular Stress Corrosion Cracking in a TL DCB Specimen from 32-mm 7049-T7351 Plate

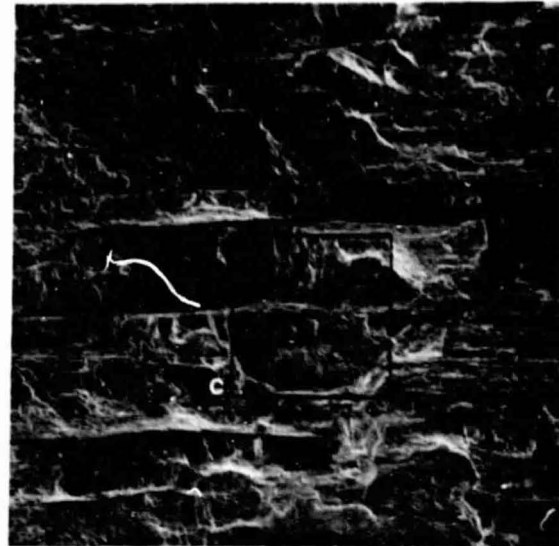
The 25-mm high specimen was exposed to marine atmosphere at Daytona Beach for 53 months. Arrow indicates intended direction of crack propagation.

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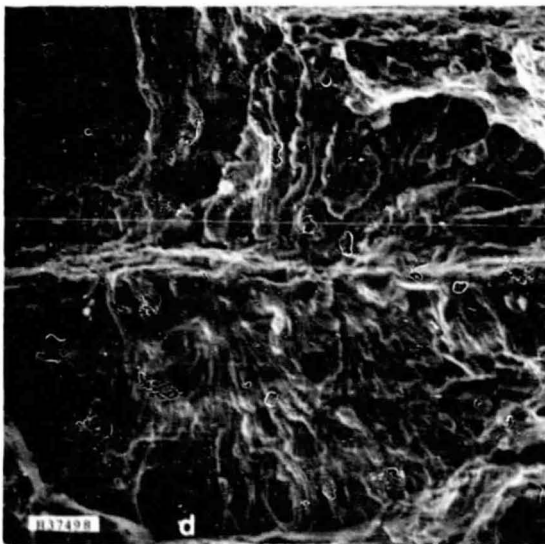
(a) ———▶

4X



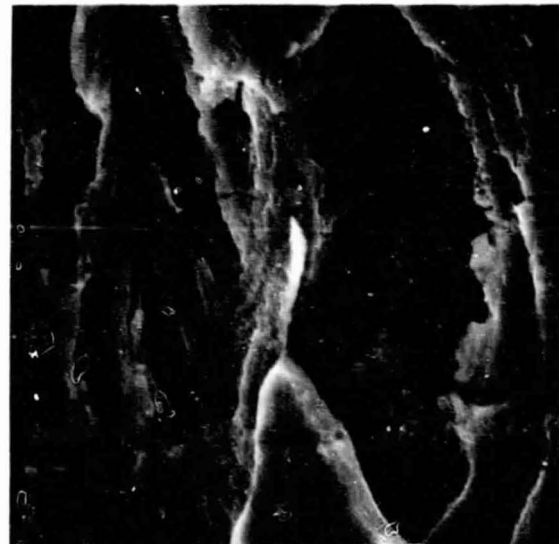
(b)

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(c)

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(d)

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Figure 13. Transgranular Stress Corrosion Cracking in a TL DCB Specimen from 76-mm 7049-T7351 Plate

The 25-mm high specimen was exposed to marine atmosphere at Daytona Beach for 53 months. Arrow indicates intended direction of crack propagation.

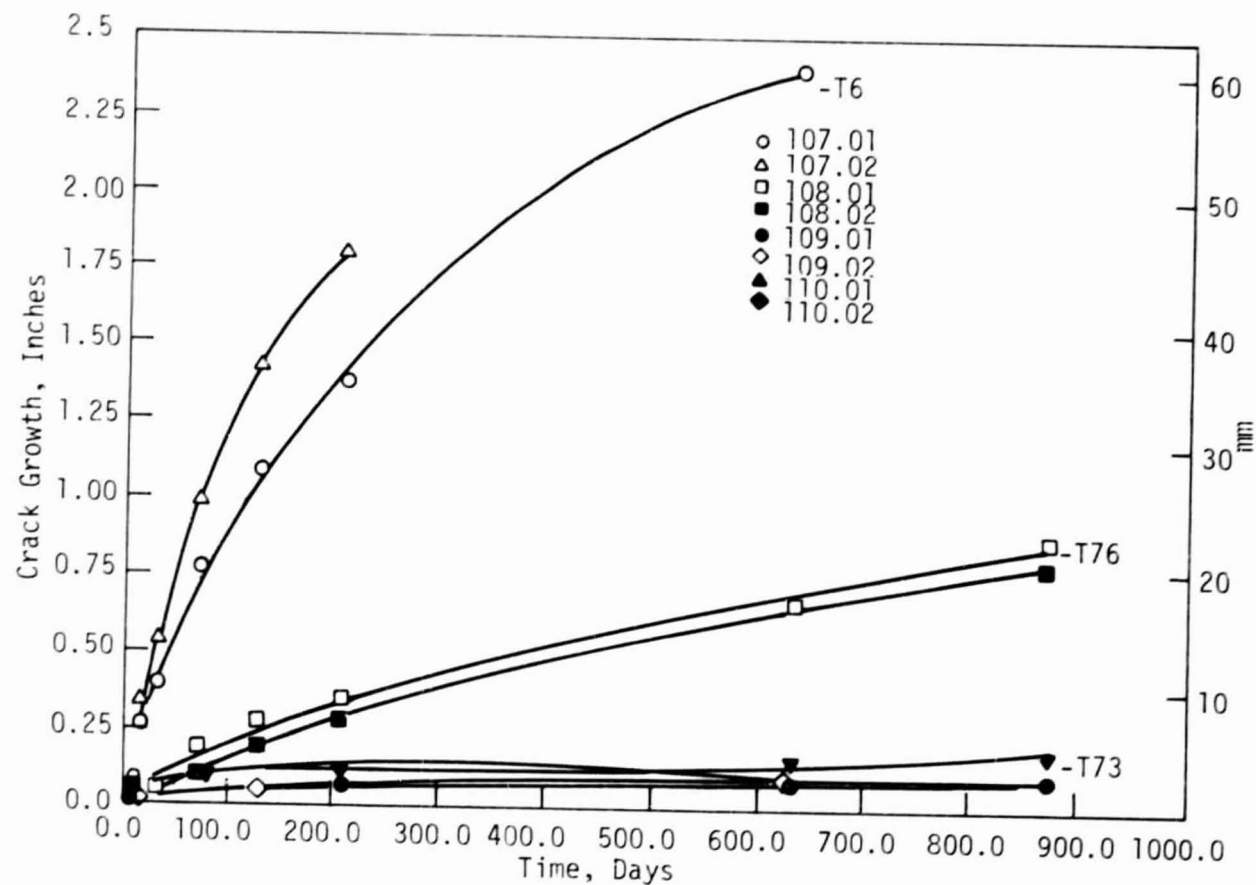


Figure 14. Stress Corrosion Crack Growth in DCB Specimens from Nominal Toughness 7475 Plate
Plate thickness SL specimens were exposed to marine atmosphere at Daytona Beach for 30 months.

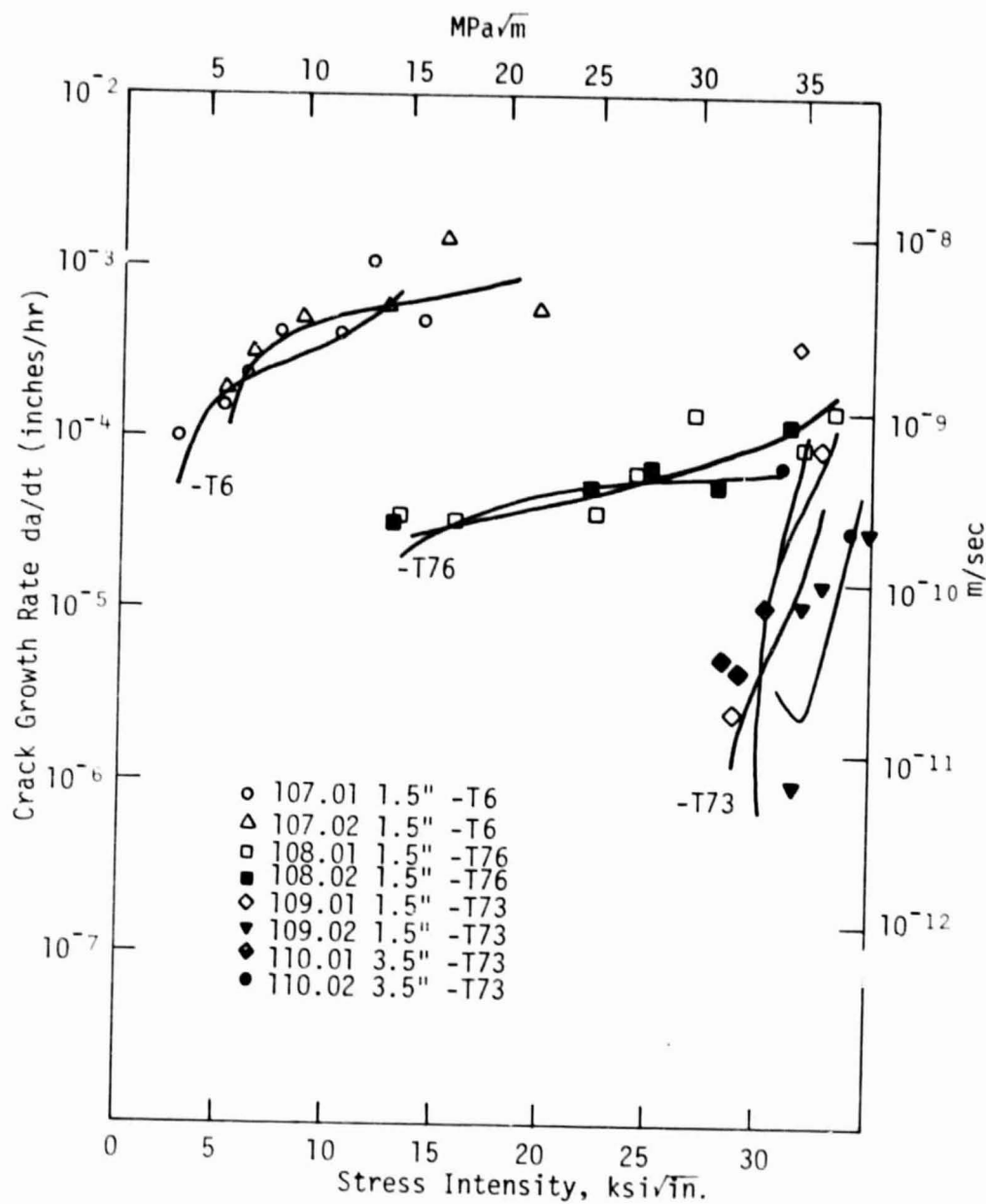


Figure 15. V-K Plots for DCB Specimens from Nominal Toughness 7475 Plate

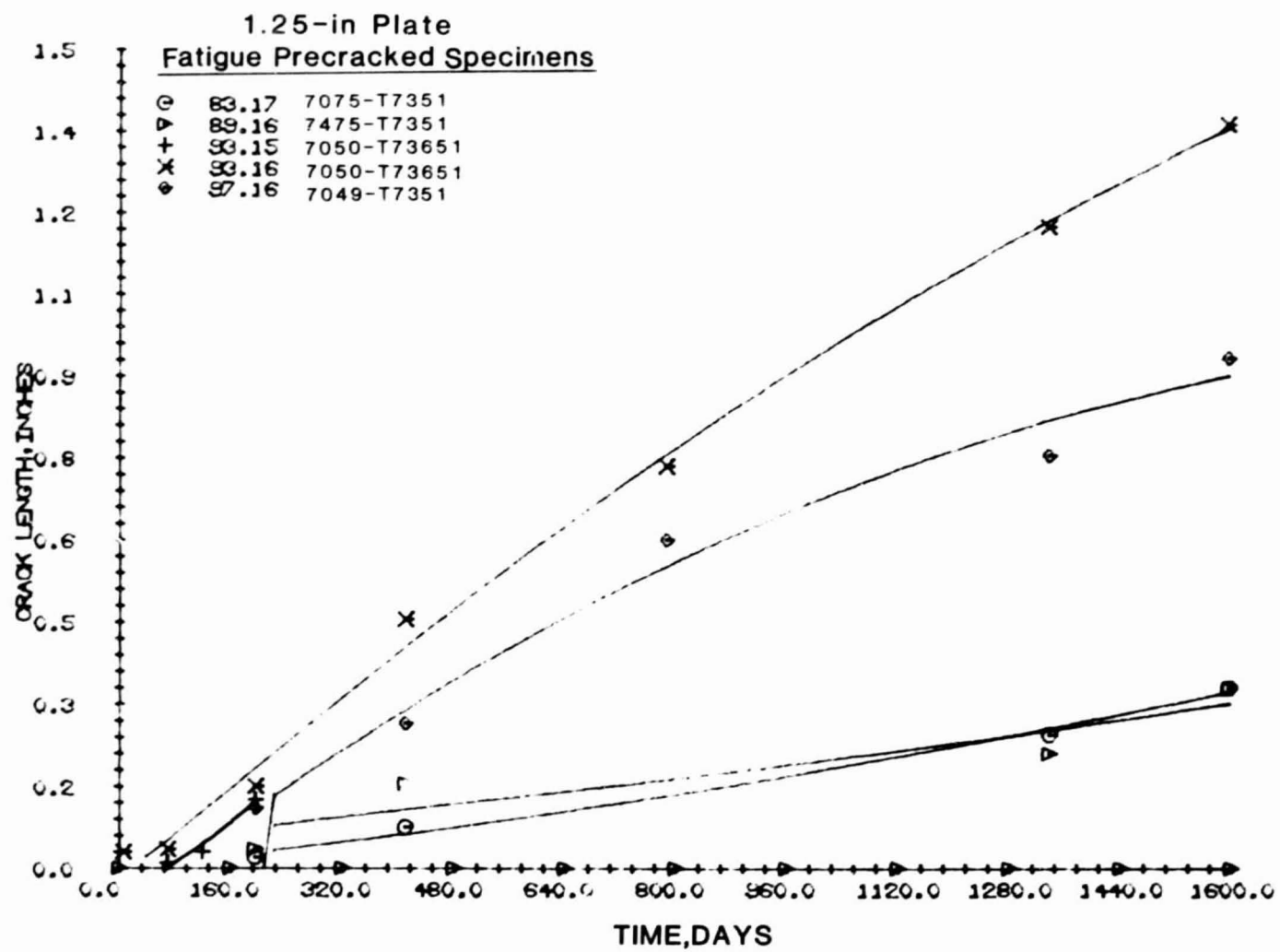
Plate thickness SL specimens were exposed to marine atmosphere at Daytona Beach for 30 months.

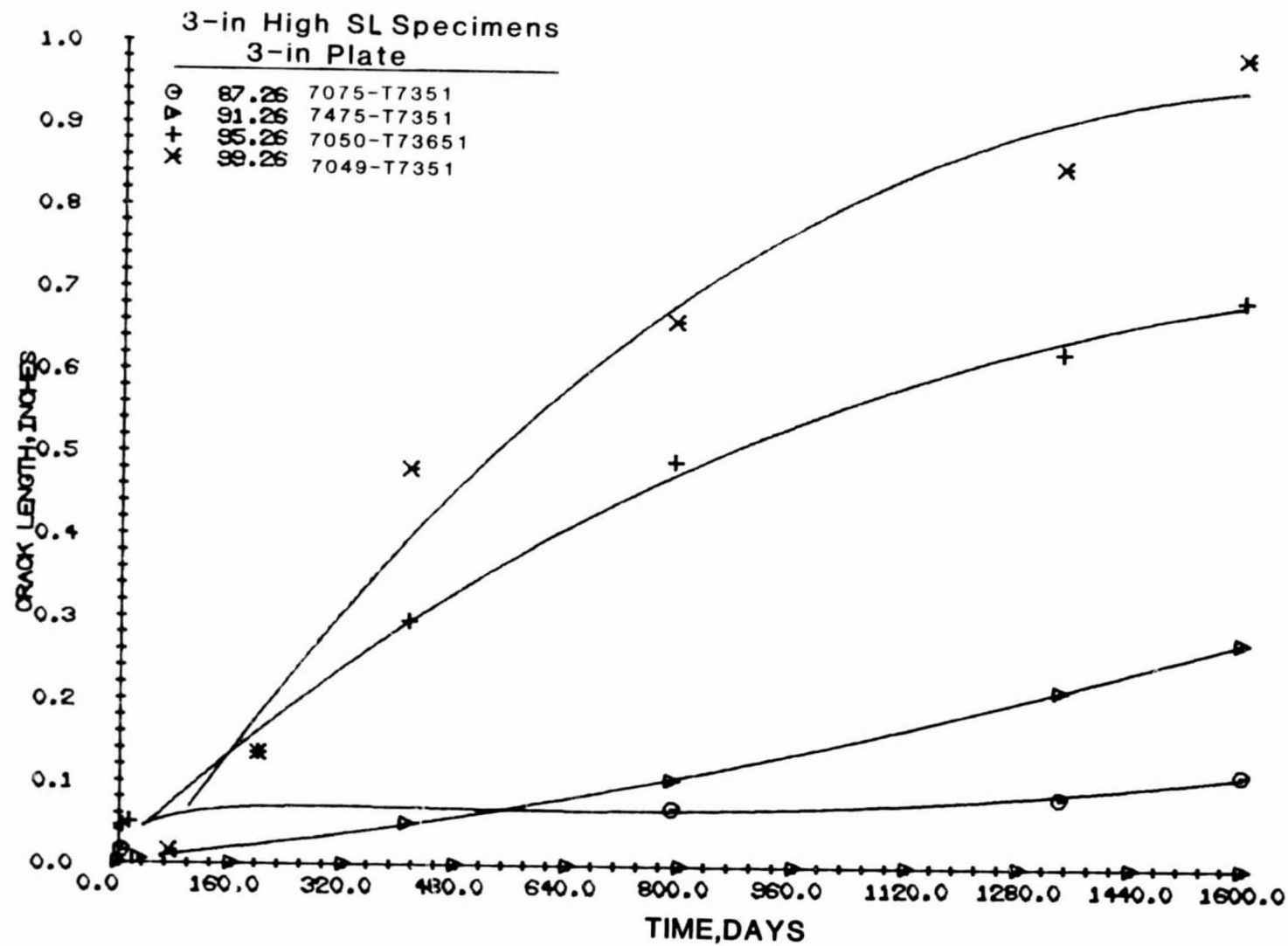
APPENDIX
COMPUTER GENERATED CRACK LENGTH/TIME AND V-K PLOTS
FOR 7075, 7475, 7050 AND 7049 DCB SPECIMENS
EXPOSED TO MARINE ATMOSPHERE

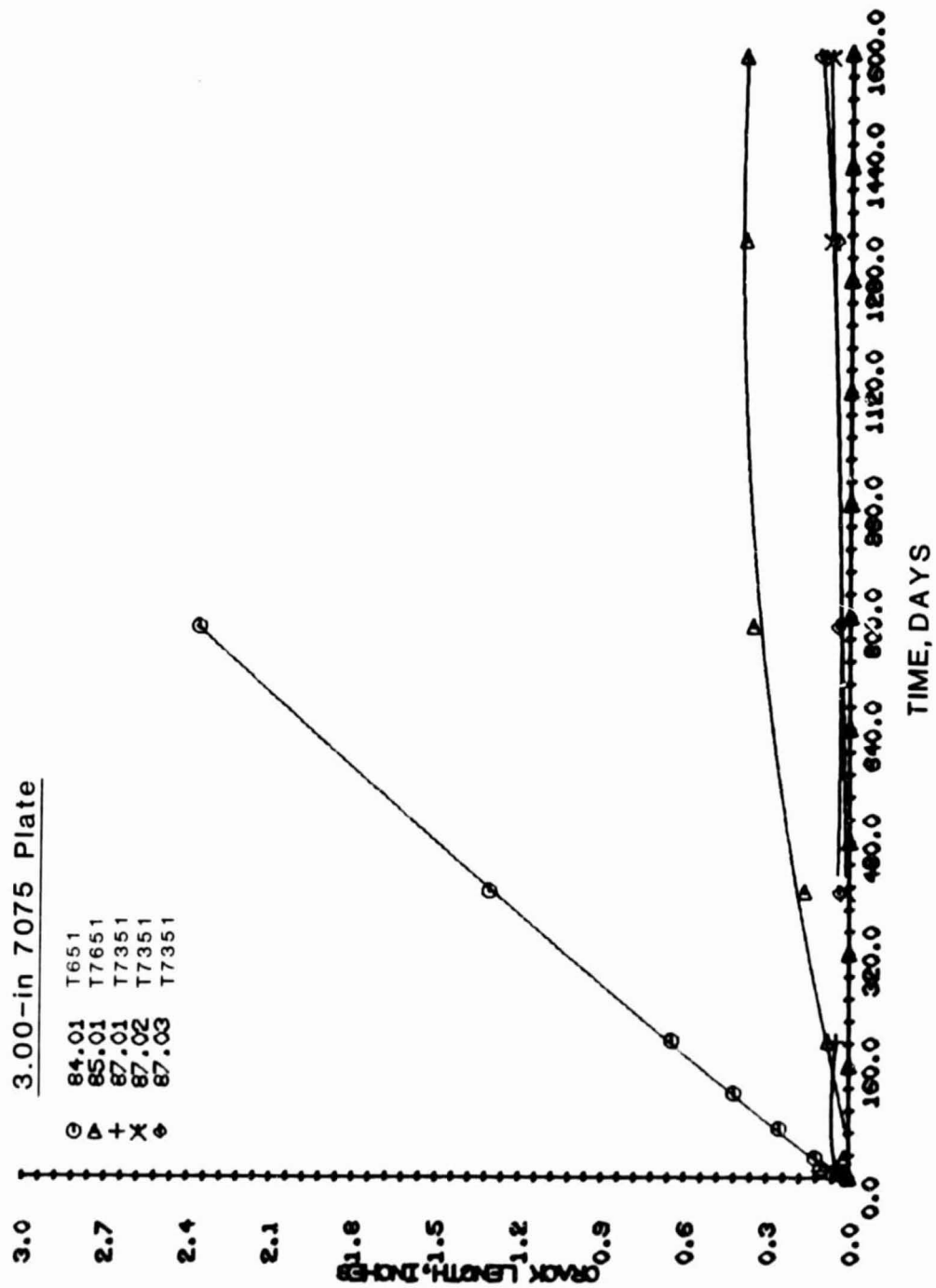
Curves were fitted to crack length time data using a transformation and polynomial regression. Stress intensities and crack growth rates (da/dt) determined from these curves were then used to construct the V-K plots. Given sufficient data and minimal scatter in the crack length data, this method provides good results.

Certain factors can bias the curves, however. For example, the first specimen in each set of triplicates was terminated after six months exposure. This test period did not provide enough data to determine the SC behavior of the resistant -T7351 temper materials. The curves for the specimens exposed only six months are therefore frequently inconsistent with those exposed for longer times. Greater apparent scatter, possibly from crack initiation effects, was a contributing factor.

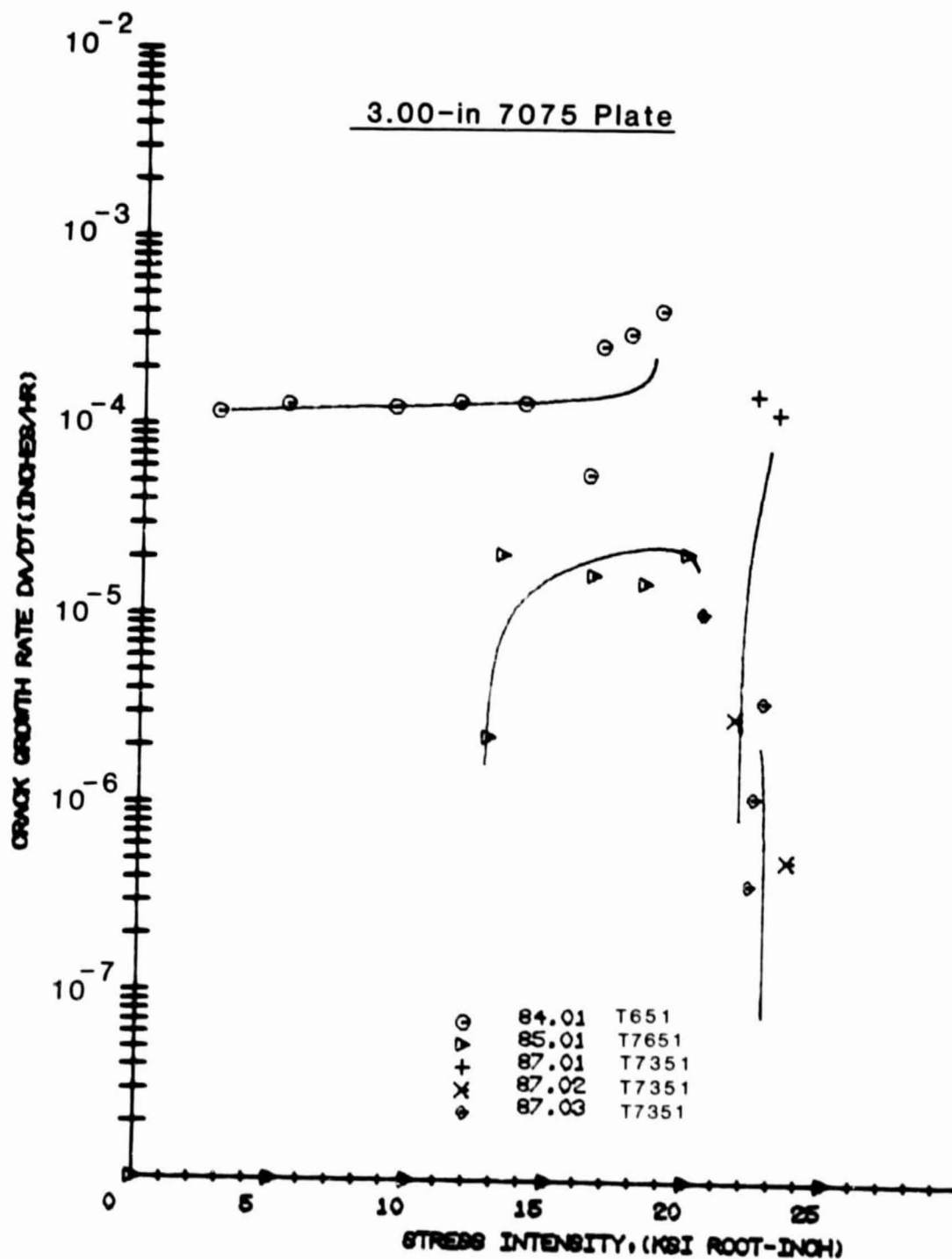
Some bias is shown in the crack length measurements taken at 44 months. All of these measurements tended to be low. This may have been a seasonal effect or the result of bias on the part of the inspector. The effects of the bias varied, depending on the overall performance of the individual specimen.

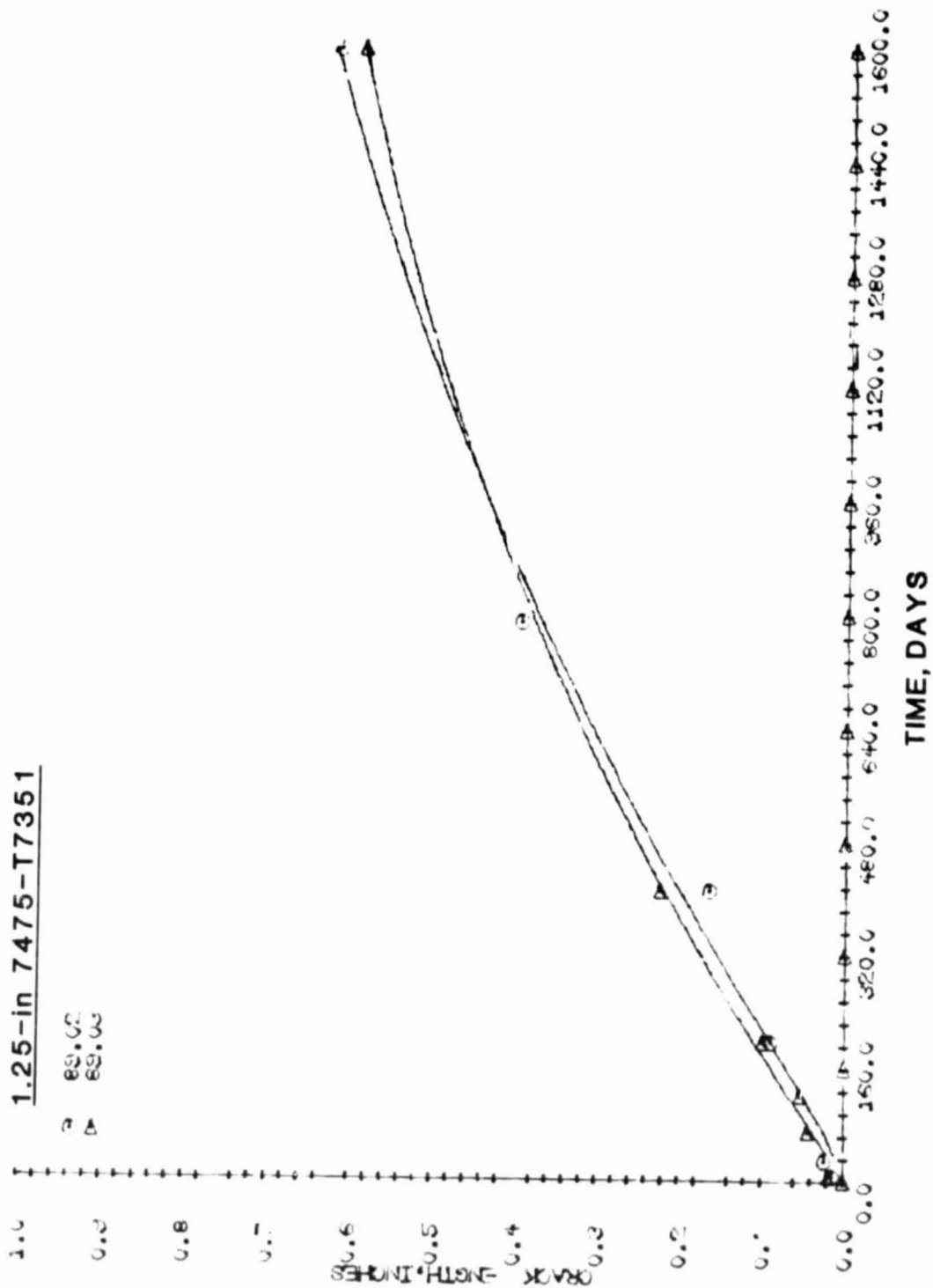


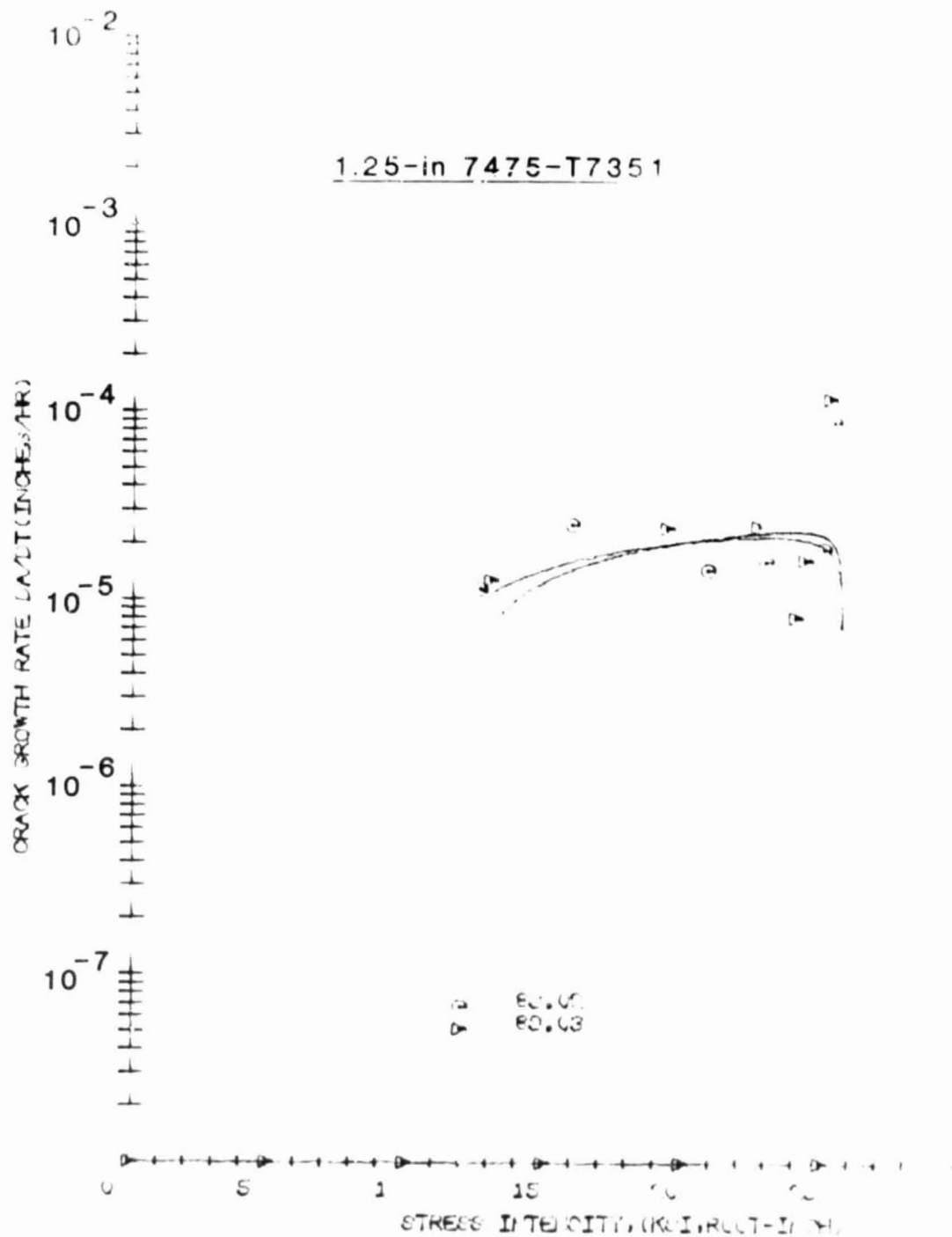


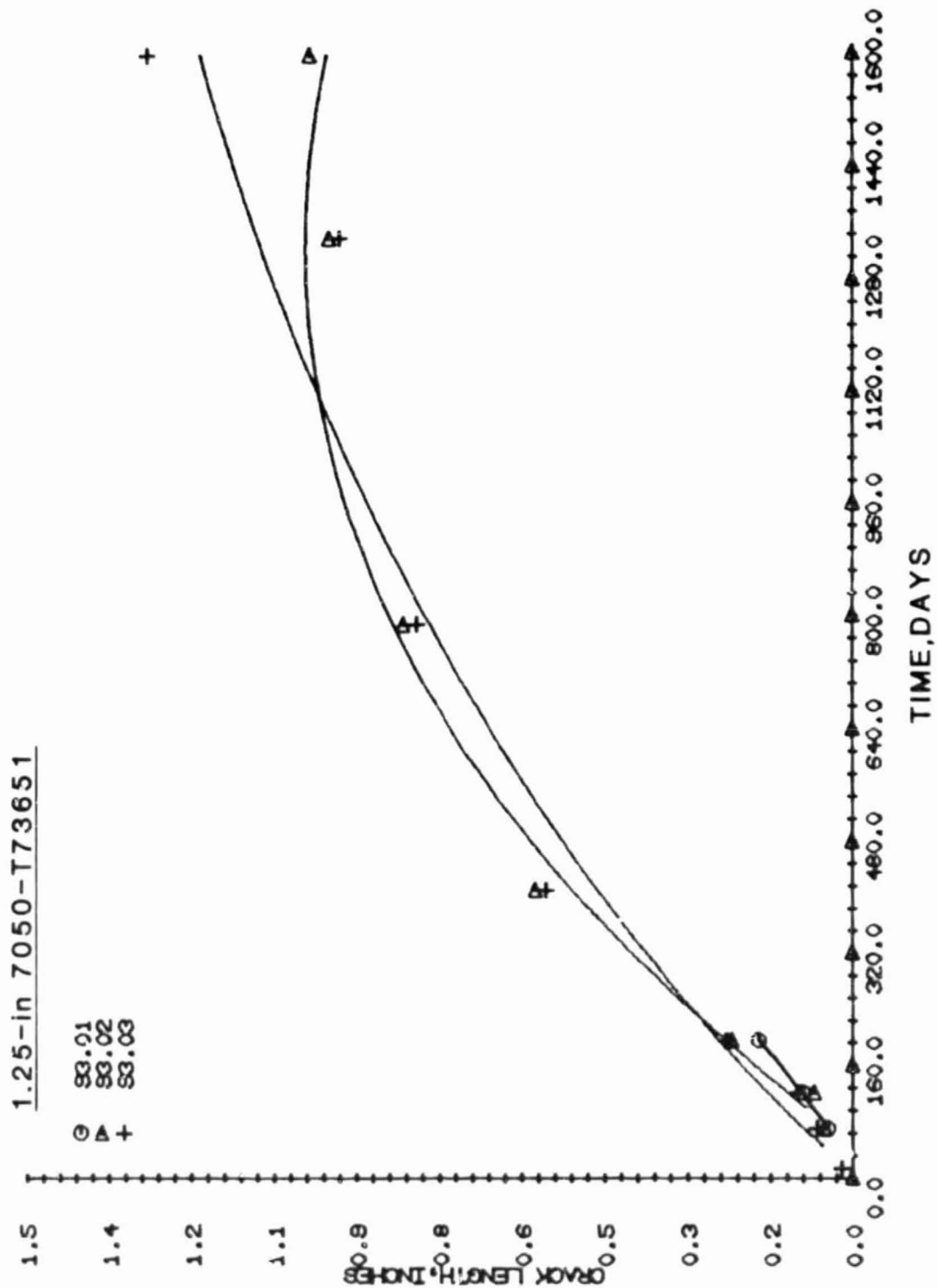


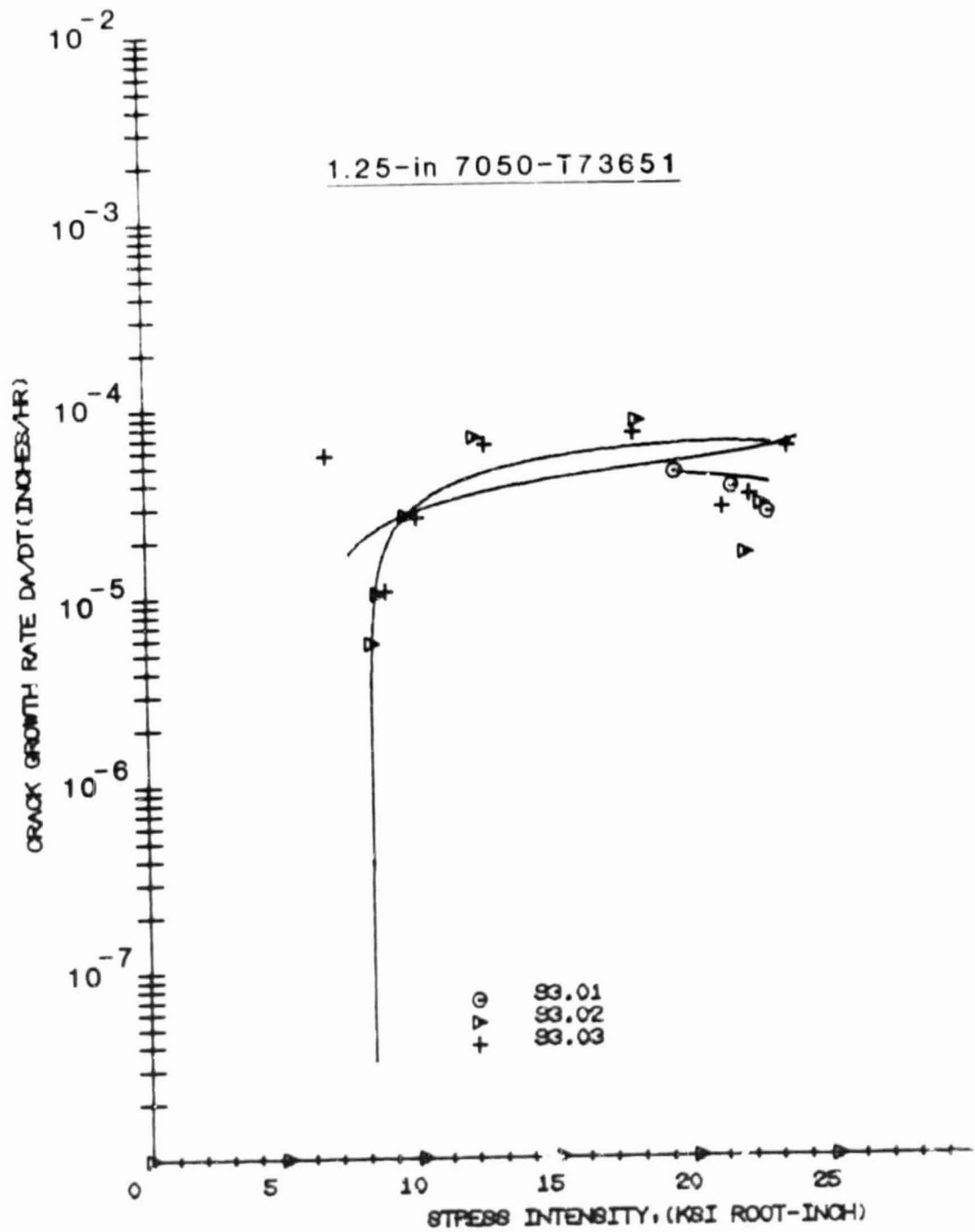
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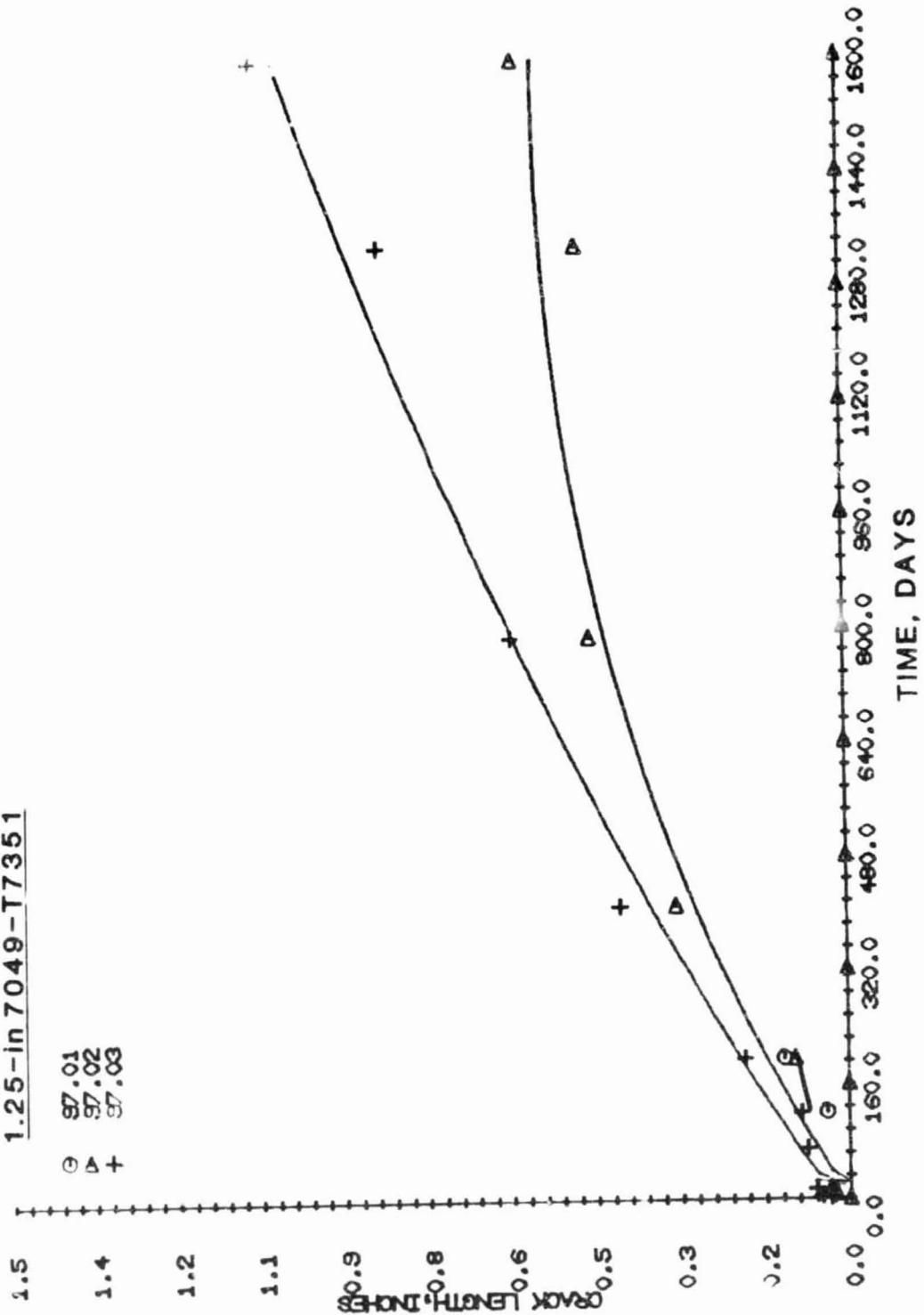


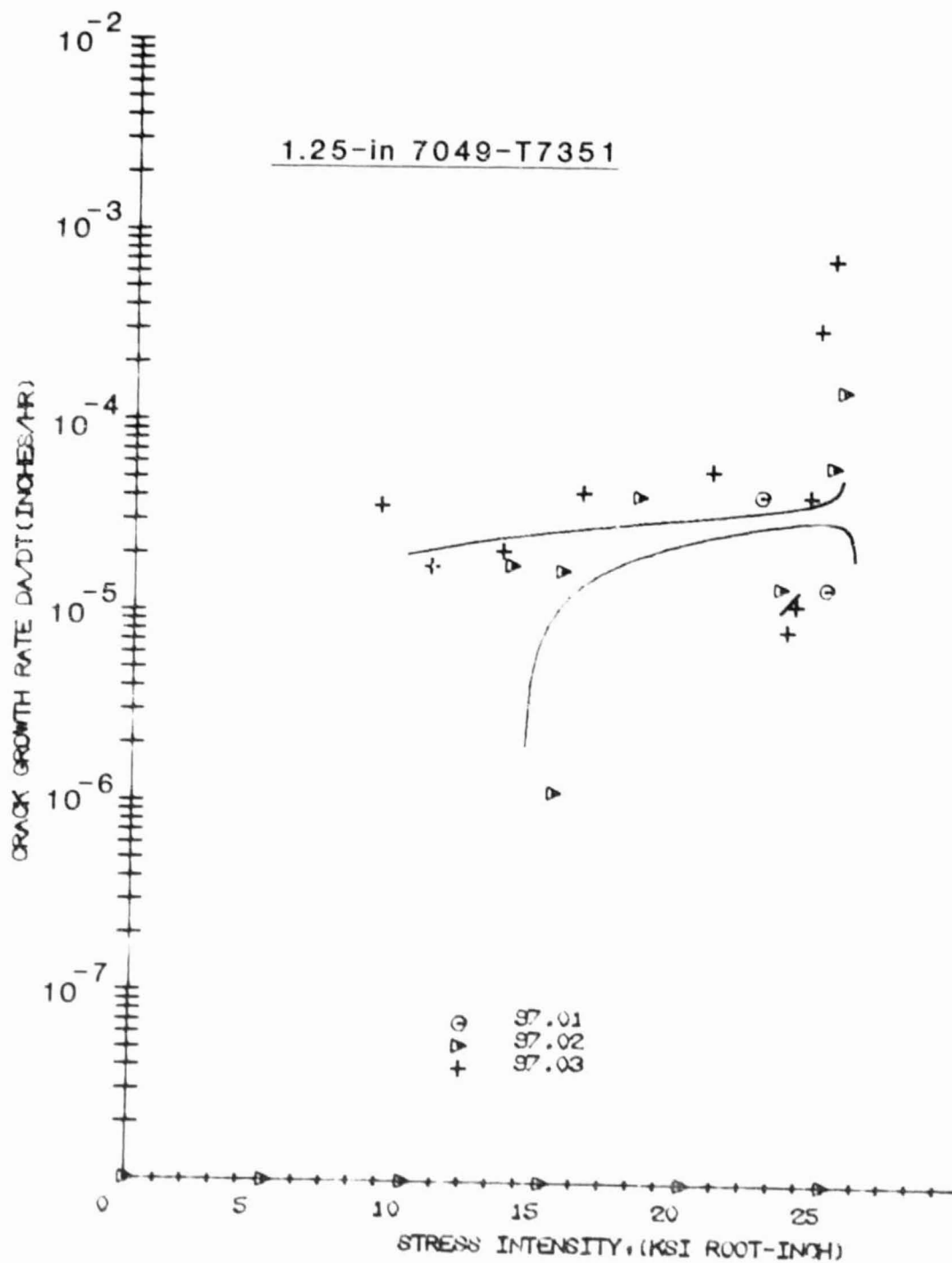


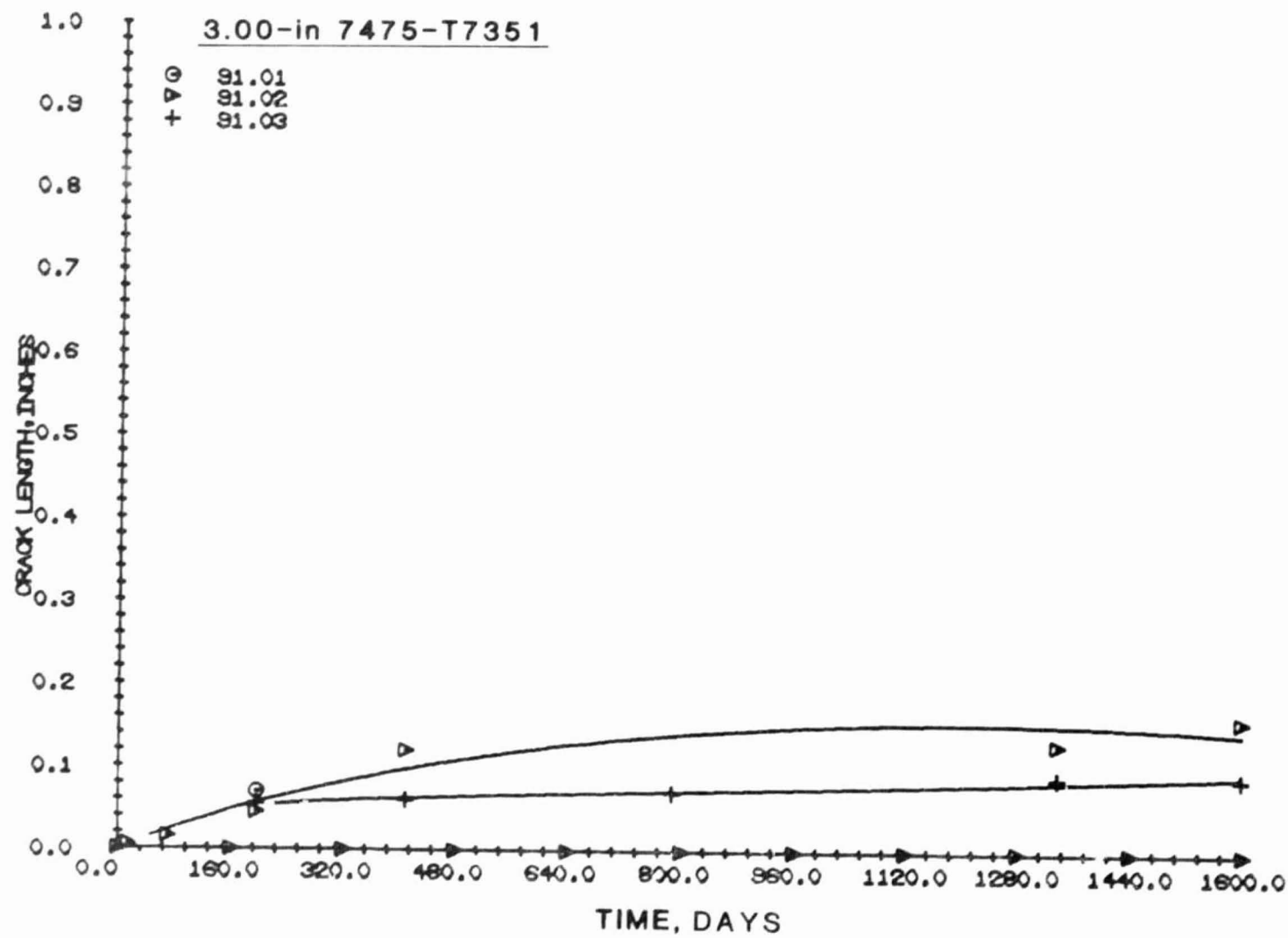


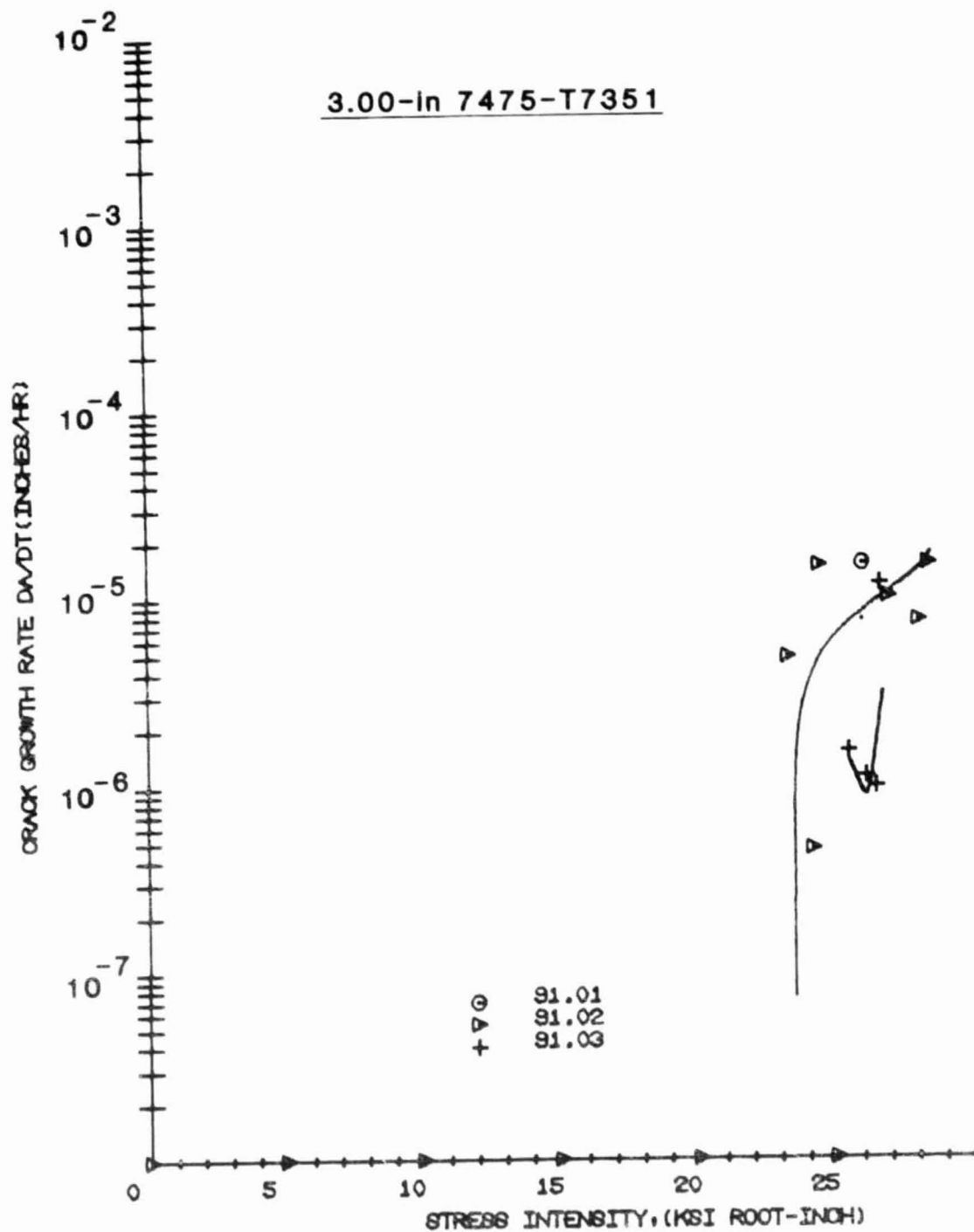


1.25-ln 7049-T7351









3.00-in 7050-T73651

35.01
35.03

